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Low-Cost Vision Edge Detection Stepper Motor Control

In this issue. . .

Happy Anniversary, *Robotics Age*! With this issue we begin our third year of publication. We've changed a lot in the two years since we started, and so has the field of robotics—not just in size, but also in character. Of course, a lot of the change can be attributed to normal growth. When we started in '79, there were only a handful of industrial robot manufacturers and robotics research groups at the universities. There was only one supplier of parts and kits specifically for the robot hobbyist. Now, the industrial market is large and diversified. Robotics has become our most rapidly growing field—easily matching the best periods in the automobile and electronics industries. Practically every major school has someone working on robots.

Although the first hobbyist-oriented company has entered the industrial arena (turning John Gallaher's early GRIVET robots into collector's items), half a dozen others have taken its place. And, with Heathkit's expected entry into the personal robot market, early in 1982, we are on the brink of a major boom in home robotics.

This issue of *Robotics Age* reflects part of the change in character the field has undergone in the last two years. Our cover feature is by Laura Conigliaro, veteran market analyst of Bache-Halsey in New York, whose studies of the industrial robot market have made international headlines. In her article, "Bullish Days in the Robot Business," she shows how her most optimistic scenario for the growth of the robot industry is fast becoming a reality.

We are also quite pleased to feature the work of the Vision Group at MIT's Artificial Intelligence Laboratory. "Edge Detection," by Ellen Hildreth, shows us how, by studying the neurophysiology of the human visual system, we can create an effective computational approach to the early stages of sight. Compared to earlier attempts, this work puts robot vision on a sound biological basis—and represents cybernetics at its best.

Rounding out the issue, Shafi Motiwala and Richard Tseng complete their presentation of "Continuous-Path Control of Stepping Motors." In this part, they discuss the key design choices behind their application of Preview Path Control to a six-axis welding robot. Also, regular *Robotics Age* contributor Don McAllister shows you a clever design you can use to build a working image digitizer with a 6-bit gray scale. All for only a few dollars in parts!

Finally, a few announcements. Time is running out for those of you who want to enter our Home Robot Photo Contest. See the announcement on page 37 of the July/August issue for details, or contact me at *Robotics*

Age. We are also planning a special issue on "Intelligent Control." This is admittedly very broad—we take it to mean any application where a microcomputer or other circuit controls some commonplace mechanism, preferably in the home or car, producing better behavior than was possible before. This could mean anything from homebrew fuel-injection to domestic energy management or security. We feel that these kinds of innovations are an important aspect of the robot revolution—and we will be bringing them to you in *Robotics Age*.

—Alan Thompson



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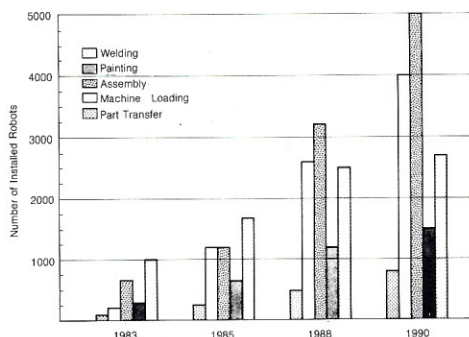
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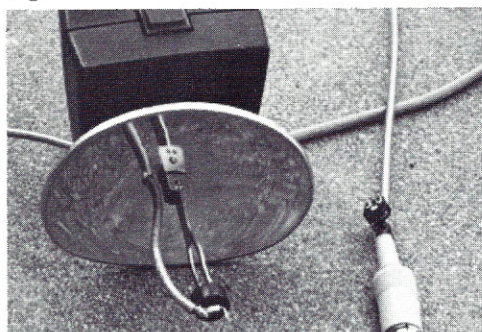
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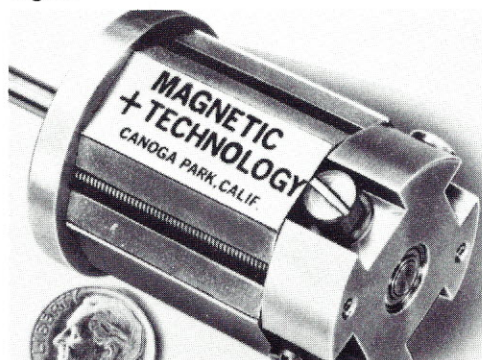




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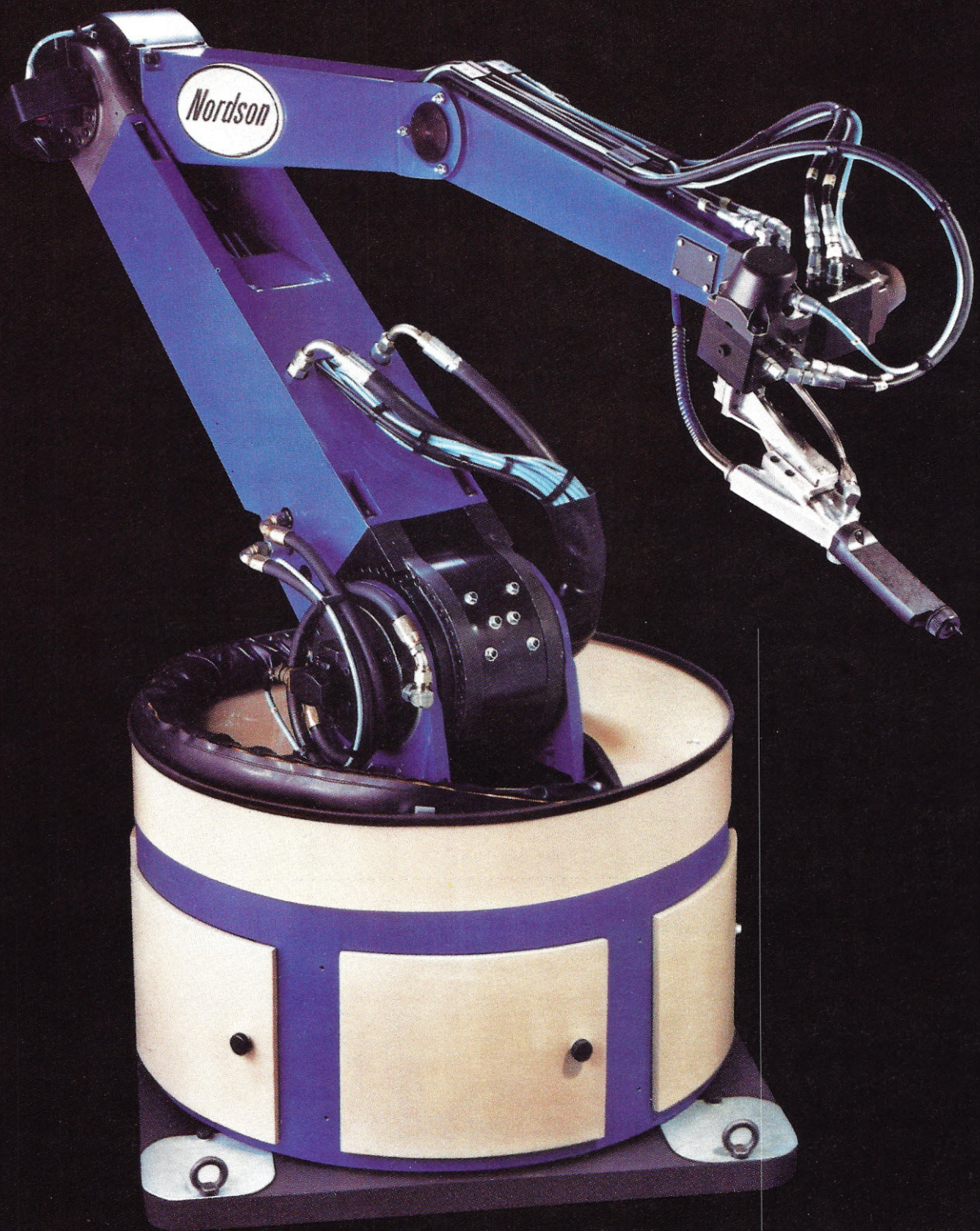
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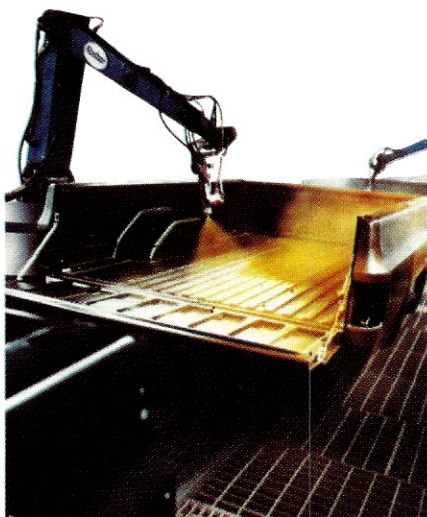
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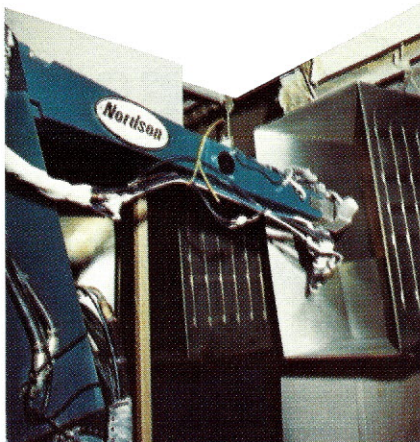
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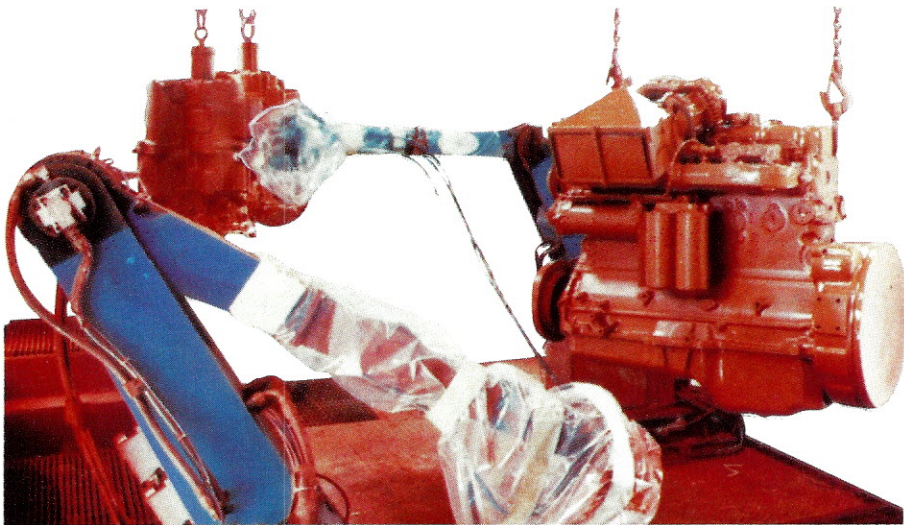
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Robotics Division

CIRCLE 23

BULLISH DAYS IN THE ROBOT BUSINESS

by

Laura Conigliaro

Analyst

Bache Halsey Stuart Shields Inc.

*There is a tide in the affairs of men
which, taken at the flood, leads on to fortune*

Shakespeare wrote those words for the play *Julius Caesar*. But today they could easily refer to the US robot industry. Like Caesar, the robot industry finds itself in a privileged position at a moment of crisis. US manufacturing is beset with problems. Its productivity is lagging. Relative to the total work force, it has a shrinking pool of workers. It faces increasingly fierce international competition. And robotics is one of the few technologies promising to solve all these problems.

It is not surprising that robots have come into their own. What is unusual, perhaps, is the enormous progress this industry has made in the last two years. Two years ago there was no comprehensive directory, no professional society, and no periodical to serve the roboticist. After reading thousands of bits and pieces about the industry, you could have concluded that robotics would be the important field in the next decade—or, just as easily, that the industry was suffering from severe delusions of grandeur.

Early Projections

Projections on industry growth spanned the entire spectrum. Some were pessimistic, some were conservative, some were optimistic, and some were downright outlandish. If you put together all the projections, you could only be sure that, by 1990, robot sales would fall between \$350 million and \$4.8 billion. Hardly a precise prediction!

Data from Japan increased the confusion. Did the Japanese have ten times as many robots as we did—or only twice as many? In fact they had both. We merely had to sort out the data by robot type to make some sense of it.

Out of this jungle of conflicting reports, I tried to predict the future of the industry. I cautiously cast my forecast in terms of two possible scenarios. See Figure 1. In the first scenario machine tool companies would continue to dominate the US robotics industry. In this case, the industry would have a compounded annual growth of around 20%. The \$60-65 million sales of 1979 would grow to about \$800 million by 1990. The number of units sold would grow more quickly, since the price per robot would decrease in time.

My second scenario assumed that major diversified companies—for instance GE, GM, and so on—entered the industry. Robots manufactured by these giants would tend to be more standardized. They would make adaptive automation available more rapidly. In this case, I estimated that the industry would grow at a compounded annual rate of slightly more than 35%. This would bring the 1979 sales base of \$60-65 million up to \$2 billion by 1990. The number of units sold would increase much more rapidly, since the majors would drastically lower the cost of each robot.

Recently, General Electric announced that it would manufacture and market the Allegro robot. With this announcement, the first major diversified company entered the arena.

Others will soon follow. General Motors, one of the largest robot users, has suggested that it plans to

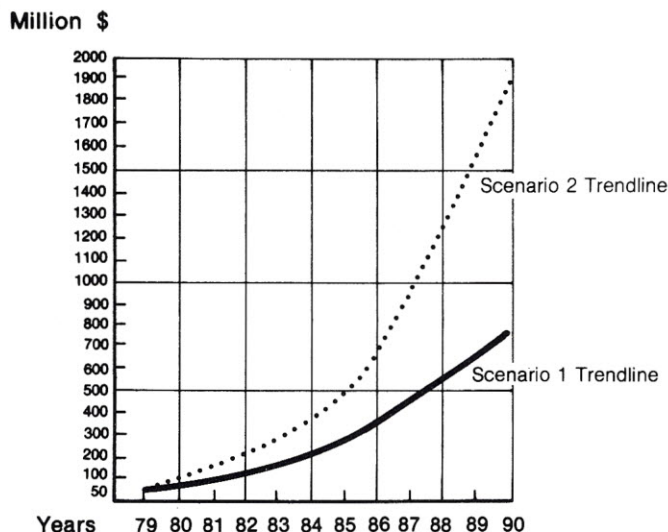


Figure 1. My early projection of industry growth was couched between two scenarios. The solid line represents how the industry would grow if machine tool companies continued to dominate it. In this case, annual growth would be about 20%. The dotted line represents how the industry would grow if major diversified companies began selling robots. Here, annual growth would exceed 35%. Since large diversified companies are entering the market, the second scenario should prove to be the more accurate one.

manufacture its own machine. GM has the experience. In 1969, they designed SAM, a six-axis manipulator. Though none are still in use, fourteen SAMs have worked in GM's plants. Now, GM plans to build a two-armed robot—one arm for painting, the other for opening and closing doors as cars travel down the assembly line.

IBM is another giant that soon may enter the market. Like GM, they have already built a robot for in-house use. It is no secret that IBM has been working on robotic technology at their facility in Boca Raton, Florida. Recently they reserved a large booth at the Robots VI trade show. At that show next March, I expect them to unveil a new robot.

GE, GM, and IBM, among others—major diversified companies—are entering the robot market. This was the precondition for my second scenario, predicting an annual growth of more than 35%. Figure 2 shows how we now expect the industry to grow. The robot rush has begun.

The Robot Rush

It's hard to ignore the signs that we are seeing bullish days in the robot business. Consider the trade shows, for example. For all the attention given to previous robotics trade shows, Robots V, held in October 1980, may well have been called Robots I. The number of people attending the technical conferences jumped from less than five

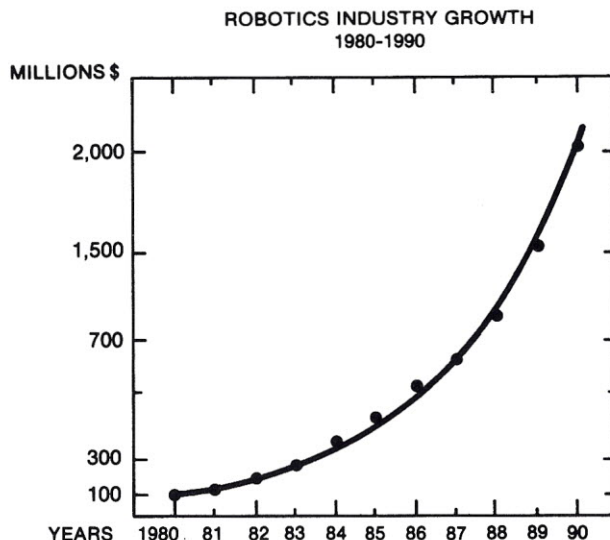


Figure 2. My current projection of industry growth.

hundred, at Robots IV, to over a thousand. More than six thousand people walked through the exhibitions at Robots V.

Established companies—those with longevity in the industry—are the first to benefit from the current boom. Although these are generally divisions of much larger publicly held companies, the robot divisions are becoming a more significant part of the whole. Although earnings from robots may be only beginning to materialize, the portion of revenue represented by robots is growing measurably.

Consider Cincinnati Milacron, nearly a \$1 billion company. We estimate that robots may contribute nearly 5% of their corporate revenue in 1981. And Cincinnati Milacron just entered the business in 1977. For Condec Corporation, Unimation's portion of corporate sales may be between 15-20%. With robot divisions growing at a much faster rate than the rest of the company, we can expect these percentages to increase.

Both public companies—and the longer list of privately held ones—are benefitting by a positive change in outlook towards them. The robot boom enables them to attract more capital—a function of the efficient flow of resources towards more attractive business opportunities.

Usually, the Wall Street community prefers to watch public companies over those that are privately financed. But many new privately financed robot companies are making Wall Street sit up and take notice. Within the last two years we have seen a multitude of new robot makers: Automatrix, Advanced Robotics, U.S. Robot, American Robot, Mobot, and Control Automation—just to name a few. Robot vision has spawned such companies as Machine Intelligence, Solid Photography (now Robotic Vision Systems), and Object Recognition Systems—with many more likely to come. It is a healthy sign that new companies are forming to provide applications engineering and software. Among these are LTI, Robot Systems,

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CIRCLE 16

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It takes more than articles of incorporation to form a new company. New companies need capital. Two years ago it was extremely difficult for small start-up firms to attract adequate financial backing. Now, venture capital firms are seeking the robot makers. For instance, InnoVen of Saddlebrook, New Jersey, operates three venture capital funds with combined assets of more than \$25 million. The investment pool, which is especially interested in robotics start-up companies, includes Emerson Electric and Monsanto among its major investors.

We estimate that since early 1980, venture capital companies have invested at least \$25 million in robotics companies alone. This figure excludes the additional investment in vision companies.

Trends in Near Term Growth

It no longer seems important to estimate the precise dollar value of the robot industry in 1990. It is more important to know the nature of industry growth over the next few years.

At this point, the industry seems to be following what is known as the "80-20 rule." That rule states that about 80%

of a company's product will go to only 20% of its customers. In the robotics industry, perhaps as much as 90% of its major orders are coming from as little as 10% of its overall customer base. This is hardly unusual for a new industry—nor is it a problem. As robots prove their worth among the upper echelons of the Fortune 500, they will gradually filter down to smaller firms.

Like the computer industry, the robotics industry will become segmented by size and by application. For the next three years or so, the major robot application will continue to be spot-welding, contributing over one-third of the total industry sales through 1982. Between 1983 and 1986, this application should plateau, and major strength will come in the areas of arc-welding, machine loading and unloading, and assembly. These will also be the largest areas in the latter part of the decade. Assembly alone might represent 35-40% of the total and over 50% of the growth for several years. See Table 1.

Using robots for assembly has been the most talked-about application. Most people have assumed that this application will develop extremely slowly, limited by the state of sensory perception technology. However, GE's first robotic product is an assembly robot system. This will certainly spur the development of other assembly systems—regardless of how quickly vision research advances. These early assembly systems will depend on an ordered (*rationalized*) factory environment, rather than advanced sensory systems. Figure 3 shows how GM projects its own robot use. By 1990, assembly will be the largest application in its factories.

TABLE 1
Estimated Robot Order Trends

	Through 1981	1990
Spot-Welding	35-45%	3-5%
Arc-Welding	5-8%	15-20%
Materials handling, including machine loading and unloading	25-30%	30-35%
Paint spraying	8-12%	5%
Assembly	10%	35-40%
Other	8-10%	7-10%

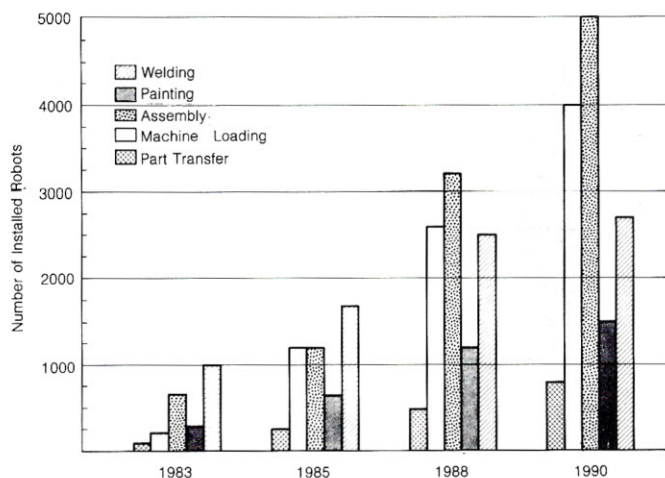


Figure 3. How General Motors projects its own use of robots, broken down by application.

The Future

As we have seen, there has been a tremendous growth in the number of new companies manufacturing robots—as well as established robot users planning to build their own machines. We could well ask: If everyone manufactures robots, who will buy them?

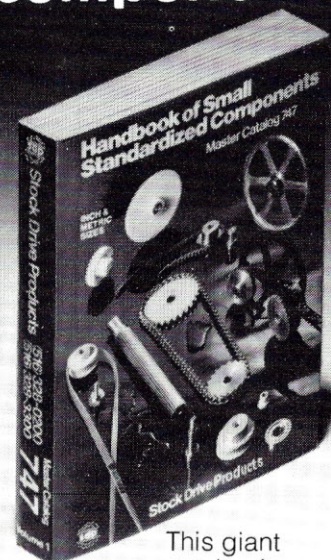
The market, obviously, will not sustain every company that manufactures a robot. So far, it has not been difficult to enter the field of robotics. The difficulty lies in broadening the initial entry into a sustainable, developing operation.

To survive in the robotics industry, companies can't afford to pour all their resources into building robot hardware. So far, robot users have typically done the applications engineering and software development on robots they have purchased. However, the robotics industry can hardly depend on its customers to supply a staff of engineers—who can massage the robot till it works—every time they buy one. With the number of competitors growing, marketing will be essential. And it may turn out that field support services will be the crucial factor that separates surviving companies from the others.

For those companies that do survive, the future looks bright. I now expect the industry to grow about 35% per year for a number of years, followed by a more moderate growth of 25-30% per year. In the film *The Graduate*, a middle-aged businessman had just one word of advice for young Benjamin Braddock. That word was "plastics." Today, he might whisper a different word to Benjamin: "Robotics." There's a great future in it. ®

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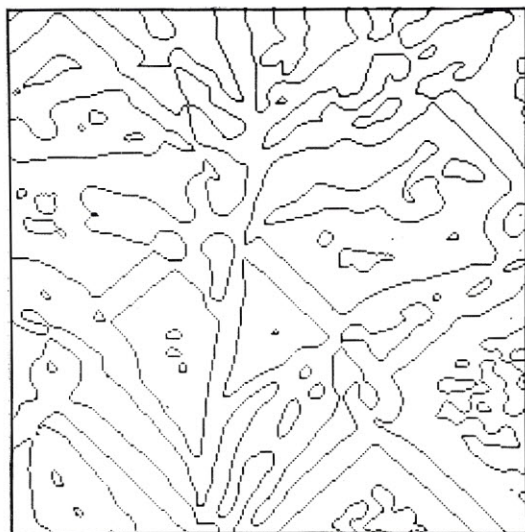
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EDGE DETECTION

IN MAN AND MACHINE



by

Ellen C. Hildreth
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Most vision systems, whether human or machine, begin by finding edges—the significant intensity changes in an image. How the vision system uses edges depends on its function. Some systems immediately begin interpreting edges as the boundaries of objects, shadow lines, and so on. With a representation of edges, we can analyze the texture, surface contours, range, and motion of objects in the image. All of these later analyses have one common starting point—the detection of edges.

The goal of creating an efficient, yet powerful, computer vision system has been pursued for many years. In most cases, however, the designers were limited by practical engineering constraints to methods that were fast and used little memory. This led to the development of specialized techniques using coarsely sampled images, very localized operators, and clever techniques for reducing the resulting problems of noise and quantization. Unfortunately, these methods often work poorly outside of their limited domains.

When we study the human visual system, though, we find that it samples the world at a high resolution and applies operators that use information from a large number of photoreceptor cells. This great processing power can overcome the limitations of specialized techniques and is one of the keys to the richness of human sight. By dedicating specialized hardware processors to the vision task we can begin to realize this level of performance in a computer vision system—provided that we have an effective *theory* that tells us how to deal with this wealth of information.

Studying the biological evidence on how the eye and brain process visual data, we can develop such a theory. The theory is significant in several respects. Not only does it suggest how a computer vision system can most effectively employ intensity information to find edges, but it leads to further understanding of the early stages of *human* visual processing as well. This article discusses the theory of edge detection developed by David Marr, myself, and other colleagues at MIT. First, though, let's look at some of the previous results—both in computer and biological vision systems—that influenced our work.

Past Approaches to Edge Detection

Mathematically, we can regard an image as a function of two variables. For every location, (x,y) , in the image, there corresponds an intensity, $I(x,y)$. Although a digitized image must necessarily be divided into discrete picture elements (pixels), normally stored in a two-dimensional array, let's consider I , to be a continuous function defined in a plane. Most computer vision systems detect edges by a *differential* analysis of the image, which I can explain in terms of this intensity function.

Taking the first derivative of the image—in effect, differentiating $I(x,y)$ —yields a new function that shows how rapidly intensity is changing at each point in the image. Since edges correspond to the largest local intensity changes, we can locate edges by finding the high points (peaks) in the differentiated image. Figures 1a and 1b illustrate this principle in a one-dimensional cross section (in two dimensions, the *gradient operator*, ∇^2 , is used).

Now suppose we differentiated the raw image twice. Points that appear as peaks in a once-differentiated image now appear as points where the twice-differentiated intensity function crosses zero. These *zero-crossings* correspond to edges in the raw image. Figure 1c demonstrates this effect.

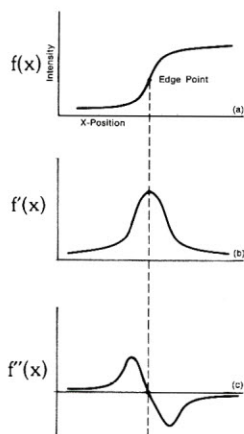


Figure 1. The principle of edge detection. Part (a) shows, for simplicity, a one-dimensional intensity function. The edge point is found where the intensity function has its maximum slope. In (b), we see the first derivative of the intensity function. The edge point can now be found at the peak of the derivative. Finally, in (c), we see the second derivative of the intensity function. Now we can find the edge point where the second derivative crosses zero—the zero-crossing.

This might be all there is to edge detection—if all edges occurred at the same scale. Unfortunately, they do not. If we look at the digitized image, the intensity changes from pixel to pixel. The boundaries of most “real-world” objects produce sharp edges—the intensity function changes steeply over a small number of pixels. In many cases, however, the edges are fuzzy; their corresponding intensity function increases gradually in smaller steps over a larger number of pixels. Edges occurring at different scales often overlap. We often find, for example, a slow intensity change due to a shading effect superimposed on a sharp, high contrast edge caused by a discontinuity in the surface.

We would like to be able to look for edges occurring at different scales. That way we can find local changes, taking place over short distances, as well as fuzzy edges in the image. We want to look at the intensity function first at a resolution near the initial image resolution and detect edges at this scale. Then, we want to *smooth* the intensity function over larger numbers of pixels and detect the edges that occur at larger and larger scales. Figure 2 shows the results of smoothing an image at different scales.

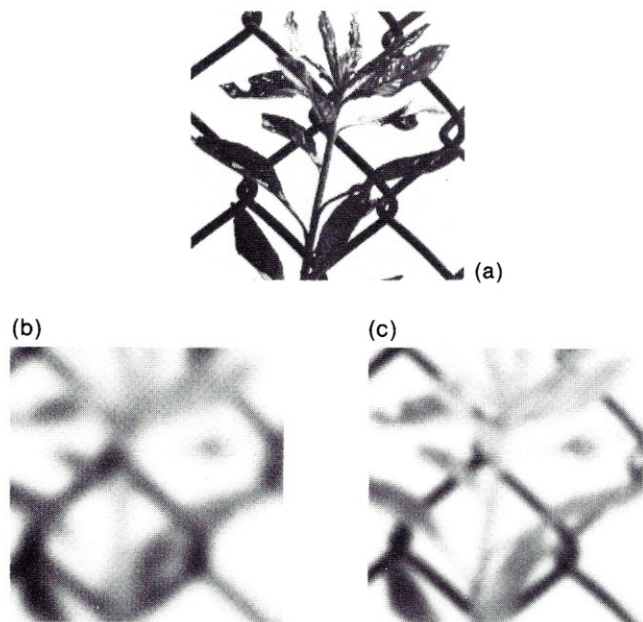


Figure 2. An image smoothed by a convolution with a Gaussian filter. The original 320×320 pixel image appears in (a). In (b) and (c) we see the original image convolved with Gaussians having scale factors of $\sigma = 4$ and $\sigma = 8$ picture elements, respectively.

Another problem is that since the real image is a discrete function, not the continuous one we assumed, the derivative operations are not mathematically defined. The solution to this problem, as well as to how to accomplish the smoothing at various scales, is realized in the process of image *convolution*. (See sidebar "Image Filtering and Convolution".) Conventional edge detection techniques commonly use an operator with a Gaussian or step-pulse profile for smoothing, combined with either first or second order differentiation to detect intensity changes, and followed by various thresholding or thinning operations. I recommend several reviews for a more thorough discussion of these methods. [2, 4, 12, 15]

We shall see now how many of these same operations are embodied in the early processing stages of the human visual system.

Insights from the Human Vision System

Human vision first registers light intensity with the array of photoreceptors in the retina. We sense images at quite a high resolution. *One square inch*, viewed from a distance of three feet, covers an array of about $200 \times 200 = 40,000$ photoreceptors in the central fovea of the eye. Several layers of cells in the retina process the detected light intensity, culminating with the output of the *retinal ganglion cells*—whose axons form the optic nerve fibers that carry information to the visual cortex.

Neurophysiological recordings in the retinas of cats and monkeys have told us that the receptive fields of retinal ganglion cells are organized as shown in Figure 3. [6,14] Light striking the center of the cell's receptive field excites the activity of the cell, while light striking the surrounding area inhibits it. We also know how the cell's sensitivity to light varies across its area. The shape of the sensitivity distribution can be described mathematically as the difference of two concentric Gaussian distributions:

$$G_1(x,y) - G_2(x,y) = \frac{1}{2\pi\sigma_1^2} e^{-\frac{r^2}{2\sigma_1^2}} - \frac{1}{2\pi\sigma_2^2} e^{-\frac{r^2}{2\sigma_2^2}}$$

where r is the radius from the center, and σ_1 and σ_2 are the spatial scale factors of the excitatory and inhibitory distributions, respectively. The significance of the scale factors will become apparent shortly. It is the *shape* of this distribution that is significant, not its absolute magnitude.

Extensive psychophysical experimentation has given us evidence about how the visual cortex processes information from the retina. Cortical cells have differing response patterns, some sensitive to orientation, others to

motion, etc. [5] Of particular interest to us are the "simple" cells, which have "bar" and "edge" shaped receptive fields, selective to the orientation of the stimulus. Our theory contends that the processing done in the retina is non-oriented, with the simple cells processing the results to find edges. [8]

There are also different *channels* of information processing, tuned to different scales of filtering. [19] The evidence suggests that there are at least four such channels, whose initial operators are also shaped like the difference of two Gaussians. The sizes of the operators are separated by an octave—if the size of the smallest operator covered w retinal cells, then the other channels would have sizes of $2w$, $4w$, and $8w$. The sizes of the operators at a particular point in the visual field increase linearly with its distance from the central fovea. The shape, size, and frequency bandwidth of these operators had considerable influence on our work.

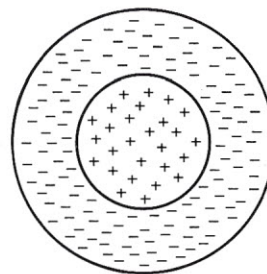


Figure 3. Receptive fields in the retina's ganglion cells have an antagonistic center-surround organization. Light falling on the central region excites the cell, while light falling on the surrounding area inhibits its output.

Marr-Hildreth Edge Detection

Our approach to edge detection came about by asking how the human visual system worked. Yet we can apply the results of our biological study to computer vision systems as well. The theory can be supported and discussed—as I am about to do—solely on computational grounds.

Recall that edge computation proceeds in three steps: The image is smoothed, differentiated, and scanned for peaks (if the first derivative is used) or zero-crossings (if the second derivative is used).

Suppose that we first smooth the image by convolving it with a Gaussian filter, as shown in Figure 3. We can describe the smoothed image symbolically as $G * I$. Our

next step is to differentiate the smoothed image. For this we can use the Laplacian operator,

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$$

The Laplacian gives a non-oriented second derivative. We can write the new image as $\nabla^2(G * I)$.

At this point, a mathematical property of the convolution comes into play:

$$\nabla^2(G * I) = (\nabla^2 G) * I.$$

This means that we can combine the ∇^2 and the Gaussian, G into a single operator, whose shape is

$$\nabla^2 G = (2 - \frac{r^2}{\sigma^2}) e^{-\frac{r^2}{2\sigma^2}}$$

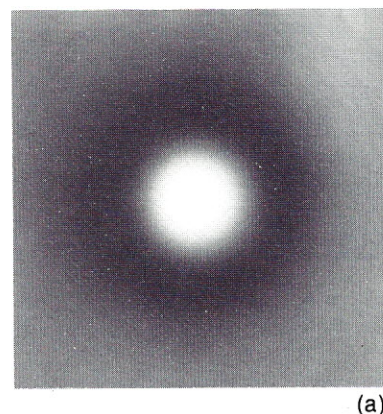
Then $\nabla^2 G$ is convolved with the image. This is the same process— $\nabla^2 G * I$ —that we believe occurs in the retina!

The $\nabla^2 G$ operator is intimately related to the Difference-of-Gaussians (DoG) profile measured in biological experiments. The shape of the DoG pattern becomes identical to that of $\nabla^2 G$ when the spatial scales of the two Gaussian profiles are close, as they are in the biological case. The $\nabla^2 G$ operator is illustrated in Figure 4. We have an edge-detector justified mathematically that is also consistent with biological experience.

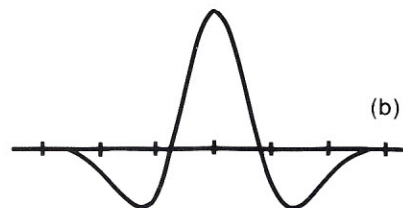
The meaning of the $\nabla^2 G$ operator should now be clear. The G part smooths the image to an appropriate scale, then the ∇^2 part performs a second order derivative. The next step is to find the zero-crossings, which may signify edges in the image. Figure 5 shows each step in our edge detection process.

Given a collection of zero-crossings, we still have to extract and represent edge evidence in a useful way. Our representation, suggested by David Marr, is called the *raw primal sketch*. [7] To create it, we chop our collection of zero-crossings into a series of short line segments. For each segment, we compute its location in the image, its two-dimensional orientation, its length, and the rate at which the $\nabla^2 G$ output changes as it crosses zero—the latter measurement is related to the contrast or sharpness of the edge.

The important properties of the $\nabla^2 G$ operator are that it is (1) localized in space and in frequency, (2) of adequate size to reduce the effects of noise, and (3) non-directional. Its spatial scale factors determine both the region within which evidence may make a contribution and the resolution or "response" of its smoothing filter. The size of the operator is important in determining its sensitivity to noise as well. The smallest operator we use in our system, having a spatial scale of $\sigma = 8$ pixels, is able to respond to a step change in intensity even with the signal to noise ratio of the image almost one!

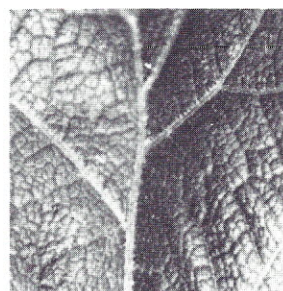


(a)

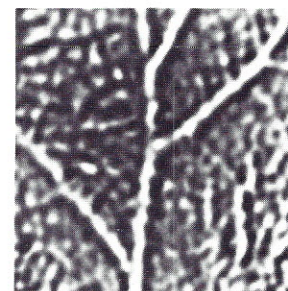


(b)

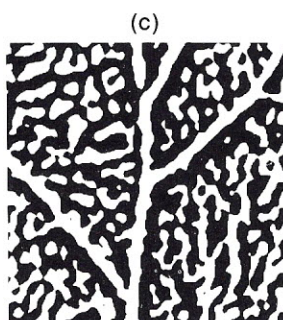
Figure 4. The $\nabla^2 G$ operator. Part (a) shows a top view of the distribution obtained by plotting its amplitude as brightness with 0 = gray. Part (b) gives a side view cross-section of the operator.



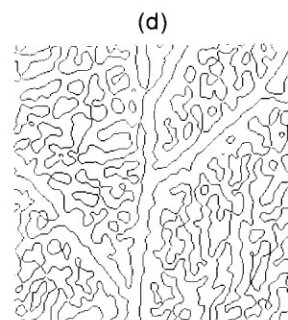
(a)



(b)



(c)



(d)

Figure 5. Edge detection. Part (a) shows a 320×320 pixel raw image. Part (b) depicts the image after it has been transformed by a $\nabla^2 G$ operator with a size $w = 9$ pixels. In this image, 0 is represented by medium gray. In (c), the positive values in the $\nabla^2 G$ output are shown as white, the negative values as black. Finally, in (d), we see the zero-crossings, the edges of the image in (a).

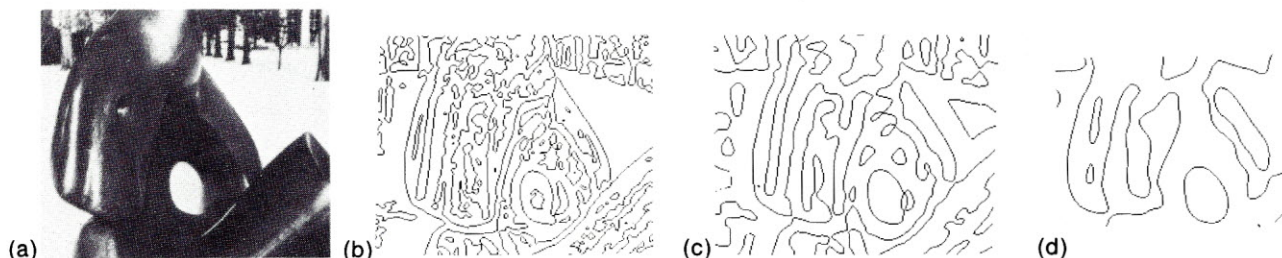


Figure 6. Zero-crossings from different sized operators. Part (a) shows the raw image. Parts (b), (c), and (d) show the zero-crossings when the image has been transformed by $\nabla^2 G$ s with sizes $w=6$, 12, and 24 pixels, respectively.

Multiple Channels of Visual Information

Suppose that we have created a number of primal sketches, each corresponding to zero-crossings detected at a different spatial scale. (Figure 6 shows edges at several different scales.) We are now faced with one of the difficult and elusive problems in edge detection: How do we integrate information from primal sketches made by different sized operators?

One possibility is to use zero-crossings at various scales to confirm the existence of edges. Zero-crossings do not necessarily correspond to a physical boundary. However, a significant edge in a scene will tend to produce zero-crossings in adjacent channels which coincide spatially. This spatial coincidence, shown in Figure 7, might serve as a criterion for establishing the existence of an edge, but there are still a number of unsolved problems. [4]

Later processes which use the primal sketch—stereopsis, motion analysis, texture computation, and so on—may also integrate primal sketches from various channels. In stereopsis, for example, the major computational problem is to match elements in the images provided by the right and left eyes (or cameras), and measure the disparity in their positions. This disparity gives us the depths of elements in the scene.

According to a recent theory of human stereo vision [9], the elements we match are the zero-crossings from different sized operators. Because zero-crossings are such simple and primitive elements, there is a significant problem with *false targets*. That is, for a particular zero-crossing in the left image, there are several candidate zero-crossings in the right image to which it could correspond. To solve this problem, the algorithm first matches zero-crossings from large operators, where the zero-crossings are less dense, and therefore contain fewer false targets over a given distance in the image. This provides a rough idea of where things are in depth. The zero-crossings from successively smaller operators refines this information. This approach has been embodied in a computer system for stereo range measurement. [3]

Studying these later processing stages may also tell us whether the information contained in the raw primal sketch is enough. Are other description primitives needed, such as bars, blobs, or terminations? For stereopsis, the zero-crossings were sufficient, but we need to explore the later operations to gain a further understanding of edge detection.

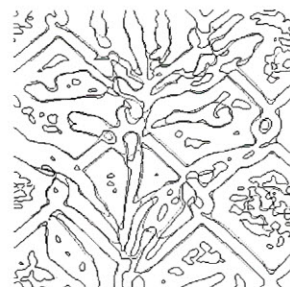


Figure 7. The spatial coincidence of zero-crossings from two different scales. Edges that represent real object boundaries tend to be found in several adjacent scales.

Conclusion

Our theory of edge detection has prompted the building of special purpose edge detection hardware [11]. We have already built a device that, in one second, transforms a 1000×1000 pixel image with difference-of-Gaussians approximation to $\nabla^2 G$. We are now building a linear array camera and a zero-crossing detector of comparable speed. With our special-purpose hardware, the performance of machine edge detection will begin to approach edge detection by the human visual system.

Though the complete "vision problem" has yet to be solved, studies of the human vision system have greatly contributed to our understanding of edge detection. These studies have shown us the importance of sampling the image at high resolution, applying a range of differential operators whose shape is $\nabla^2 G$, and detecting the zero-crossings in the operator's output. The result is an edge detection scheme which is simple, efficient, and can be applied to computer vision—using present technology. The computational study of human vision, which began to blossom with the work of David Marr, will continue to provide insights for the development of general computer vision systems. □

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IMAGE FILTERING AND CONVOLUTION

One of the basic operations of image processing is to filter an intensity array to reduce the effects of noise and quantization. By adjusting the "response" of the filter, the same technique will smooth the image at various scales to reduce the effect of edges more narrow than the scale of the filter. One simple way to smooth an image is to average the intensity of the pixels in the neighborhood of a given image location and use the result as the intensity at that point in the smoothed image.

Figure (a) shows a 3×3 image filter "window", centered at location (i,j) in the image, where the intensity is $I(i,j)$. In the smoothed image, the new intensity of (i,j) will be

$$S(i,j) = \frac{1}{9} \sum_{u=-1}^1 \sum_{v=-1}^1 I(i-u, j-v).$$

Now, let's rewrite this equation in a slightly different form. First, let $f(i,j) = 1/9$ if both i and j lie between -1 and 1 (inclusive) and 0 otherwise. Then, $S(i,j)$ can be rewritten:

$$S(i,j) = \sum_u \sum_v f(u,v) I(i-u, j-v).$$

Mathematically, this double sum is a discrete convolution, where the image— $I(i,j)$ —is convolved with the "operator" $f(i,j)$. Mathematical readers will recognize this equation as the discrete form of the two-dimensional convolution integral

$$S(x,y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(u,v) I(x-u, y-v) du dv.$$

In mathematical shorthand, "*" is used as the symbol for convolution. In the previous equation, $S = f * I$.

By writing $S(i,j)$ in the form of a convolution, we can explicitly see the characteristics of the operator that smooths the image. The operator's shape and size are two of these characteristics. Shape simply refers to the kind of function (say a sine function) that describes the operator. An operator's size is the number of points that contribute significantly to the output of the convolution. The shape of our $f(i,j)$ operator is a step pulse with a width of 3 pixels (in the discrete space). (See (b).)

Operators of certain other shapes can also be convolved with an image to smooth it. One such operator is the 2-D Gaussian,

$$G(x,y) = 2\pi\sigma^2 e^{-(x^2 + y^2)/2\sigma^2}$$

where σ is a scale factor that determines the operator's width. Figure (c) shows a one-dimensional version of the Gaussian. Figure 2 in the text shows how images can be smoothed by convolving them with Gaussian operators of different sizes.

Most methods of edge detection in gray scale pictures are based on some form of convolution. They filter the image to smooth it, apply differential operators to the smoothed image, then detect edges as peaks or zero-crossings. Convolution has an important property that greatly simplifies this process. It allows an image differentiation to be combined with the smoothing process and performed in one "pass" of the image.

To understand why this is so, let's look at the first derivative of a one-dimensional convolution:

$$(f * g)' = \frac{d}{dx} \int_{-\infty}^{\infty} f(t) g(x-t) dt.$$

Since only the function g depends on x , the derivative operation passes through the integral and acts only on g , so that

$$(f * g)' = \int_{-\infty}^{\infty} f(t) g'(x-t) dt = f * g'.$$

If now we make the change of variable $s = x-t$, we can rewrite the undifferentiated convolution integral as

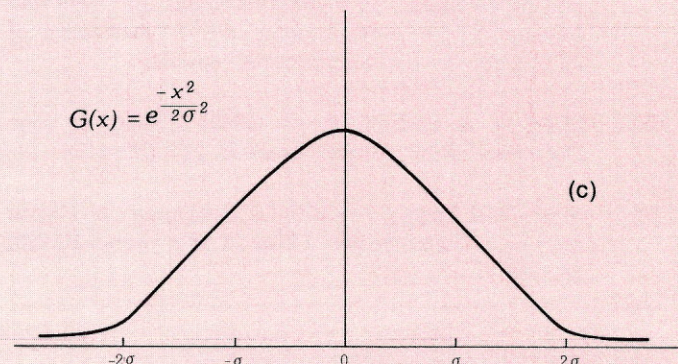
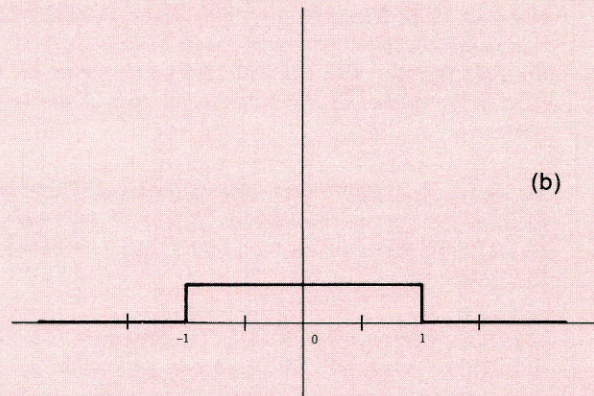
$$f * g = \int_{-\infty}^{\infty} f(x-s) g(s) ds,$$

where $x-t$ replaces t as the parameter of f . Taking the derivative of the convolution as before, we see that, since now only the function f has a dependence on x , $(f * g)' = f' * g$ as well.

This result is important, for it means that to smooth the image and differentiate it at the same time, we can simply convolve it with the derivative of the smoothing operator. This gives us a way to define differentiation on the discrete digitized image array—and it is the key to using the $\nabla^2 G$ operator discussed in the text.

$(i-1,j-1)$	$(i-1,j)$	$(i-1,j+1)$
$(i,j-1)$	(i,j)	$(i,j+1)$
$(i+1,j-1)$	$(i+1,j)$	$(i+1,j+1)$

(a)



References

- [1] "Inferring Surfaces from Images." *Artificial Intelligence Journal*, Vol. 16, Special Issue on Computer Vision, J. M. Brady (ed.). *Interesting work on the interpretation of edges in a single, static image, and their constraint on surface structure.*
- [2] Davis, L. (1957) "A Survey of Edge Detection Techniques." *Computer Graphics and Image Processing* 4, 248-270.
- [3] Grimson, W. E. L. (1981) *From Images to Surfaces: A Computational Study of the Human Early Visual System*. MIT Press, Cambridge, Ma. *An in-depth computational study of the Marr-Poggio stereo algorithm, and the interpolation of full surface descriptions from sparse data. It is an excellent example of the computational approach to studying human vision.*
- [4] Hildreth, E. C. (1980) "Implementation of a Theory of Edge Detection." MIT TR-579. *Contains further discussion of the work described in this article, as well as an extensive review of other edge detection schemes.*
- [5] Hubel, D. H. & Wiesel, T. N. (1968) "Receptive Fields and Functional Architecture of Monkey Striate Cortex." *J. Physiol. (Lond.)* 195 215-243. *Presents some of the pioneering studies of the behavior of cells in the visual cortex.*
- [6] Kuffler, S. W. (1953) "Discharge Patterns and Functional Organization of the Mammalian Retina." *J. Neurophysiol.* 16, 37-68. *A pioneering study of the behavior of cells in the retina.*
- [7] Marr, D. (1981) *VISION*. W. H. Freeman Co. San Francisco (in press). *An excellent exposition of the computational approach to understanding human vision. It integrates studies of computation, neurophysiology, and psychophysics in a way that spans the depth and breadth of our present knowledge of processing of information by the human visual system.*
- [8] Marr, D. & Hildreth, E. C. (1980) "Theory of Edge Detection." *Proc. R. Soc. Lond. B.* 207, 187-217.
- [9] Marr, D. & Poggio, T. (1979) "A Computational Theory of Human Stereo Vision." *Proc. R. Soc. Lond. B.* 204, 301-328.
- [10] Marr, D., Poggio, T., & Hildreth, E. (1980) "The Smallest Channel in Early Human Vision." *J. Opt. Soc. Am.* 70, 868-870.
- [11] Nishihara, H. K. (1981) "Intensity, Visible Surface, and Volumetric Representation," *Artificial Intelligence Journal*, Vol. 16, Special Issue on Computer Vision, J. M. Brady (ed.).
- [12] Pratt, W. (1978) *Digital Image Processing*. John Wiley & Sons, N.Y.
- [13] Richter, K. & Ullman, S. (1980) "A Model for the Spatio-temporal Organization of X and Y-type Ganglion Cells in the Primate Retina." MIT AI Memo 573. *One of the first studies to take a computational theory, and show how it is implemented in neurophysiological structures; this both provides additional support for the theory, and explains the function of these structures in early visual processing.*
- [14] Rodieck, R. W. & Stone, J. (1965) "Analysis of Receptive Fields of Cat Retinal Ganglion Cells." *J. Neurophysiol.* 28 833-849. *One of the earliest studies to describe the shape of the receptive fields of retinal cells.*
- [15] Rosenfeld, A. & Kak, A. (1976) *Digital Picture Processing*, Academic Press, New York.
- [16] Tennenbaum, M. & Barrow, H. (1978) "Recovering Intrinsic Scene Characteristics from Images." in: *Computer Vision Systems*, A. R. Hanson & E. M. Riseman (eds.). Academic Press, N. Y.
- [17] Ullman, S. (1979) *The Interpretation of Visual Motion*. MIT Press, Cambridge, Ma. *An excellent example of the computational approach to understanding the human visual system.*
- [18] Westheimer, G. (1977) "Spatial Frequency and Light-spread Descriptions of Visual Acuity and Hyperacuity." *J. Opt. Soc. Am.* 67 207-212. *Westheimer has been the primary contributor to our understanding of acuity and hyperacuity in the human visual system.*
- [19] Wilson, H. R. & Bergen, (1979) "A Four Mechanism Model for Threshold Spatial Vision." *Vision Res.* 19, 19-32. *Presents a quantitative psychophysical study of the spatial frequency channels in human vision, as well as references to other work in this area.*

ROBOTICS AGE provides some discussion of edge detection in Thompson's "Introduction to Robot Vision" (Summer 1979) and Wilf's "Chain-Code" (March/April 1981).—ed.

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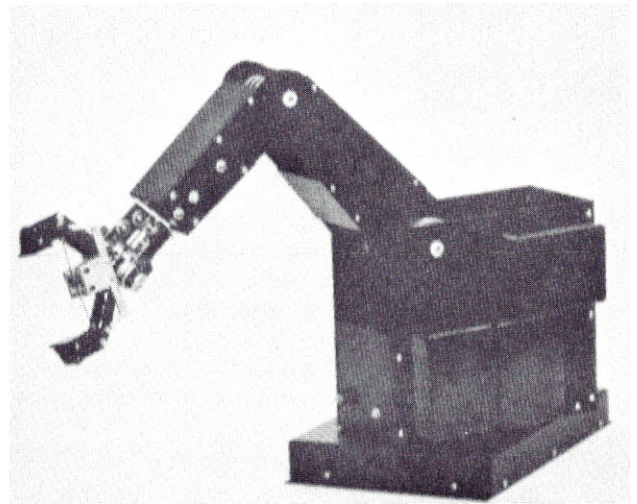
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CONTINUOUS PATH CONTROL WITH STEPPING MOTORS

by
Shafi Motiwalla
General Electric Company
Schenectady, New York

and
Richard Tseng
Measurex Corporation
Cupertino, California



Part Two: Hardware and Software Implementation for Continuous Path Control

In Part I, we showed how a robot arm driven by stepping motors can accurately track a continuous path in space, using the motors in their slewing mode. The slewing mode gives you the fastest stepping rates you can get from the motor, whereas in the "single-step" mode, the motor and its load must come to rest after each step. By limiting the motor's acceleration you can even drive the motor "open-loop" without missing steps. With the *Preview Path Control* scheme, the robot can use "look-ahead" evidence from either a path-tracking sensor or from a preprogrammed path stored in memory. This approach can give you performance comparable to that of feedback-controlled servo motor robots, but for far less effort and expense.

In this article, we will discuss some of the details involved in building a working system based on the *Preview Control* method. In particular, we will describe some of the circuitry and software techniques we used in a two-axis welding positioner controlled by a microcomputer. Rather than trying to document our entire system we

will concentrate only on some of the key design choices, including the sequencing logic, the mechanical design, the interface to the computer and a joystick controller, and the method of limiting acceleration.

The Sequencing Logic

The windings of a stepping motor must be pulsed in a particular sequence to cause the motor to move in a given direction. (See the discussion of stepping motor design in Part I.) Generating these pulses is the function of the sequencing logic, which can be implemented either in hardware or software. Our goal was to control the entire robot with a single micro. And given the burden of the path control computations, we decided to perform the pulse sequencing in hardware.

There are two basic types of pulse sequences that will cause the motor to step. In *wave drive*, only one phase of the stator winding is powered at a time (Figure 1a). In the

other sequence, called *two-phase drive*, two stator phases are energized simultaneously (Figure 1b). With two windings providing power, the latter step sequence will produce a greater torque output from the motor. Thus, it is the most commonly used of the two sequencing methods. Either of these sequences will cause an N degree/step motor to take a full step, although there is an angular offset of $N/2$ degrees between the actual position of the steps on the motor's shaft.

This half step difference between the outputs produced by the two sequences is the key to a third method of sequencing that combines the two basic types. A drive that alternates between wave drive and two-phase drive will cause the motor to take steps of half the usual increment. Reference [2] gives working circuits for all three types of sequencing logic. (A circuit for two-phase drive is given in "A Homebuilt Computer-Controlled Lathe," in the May/June '81 issue of *ROBOTICS AGE*—ed.) Half-step drive doubles the position resolution of the motor and produces smoother slow-speed motions. Also, as shown in Figure 2, it has the useful feature of reducing the effects of mechanical resonance in the motor.

Two successive steps produced by a half-step driver have differing characteristics that can result in missed steps when the load is near the limit. This motivated us to build a sequencer that would let us select either two-phase or half-step drive, so that we could experiment with both types.

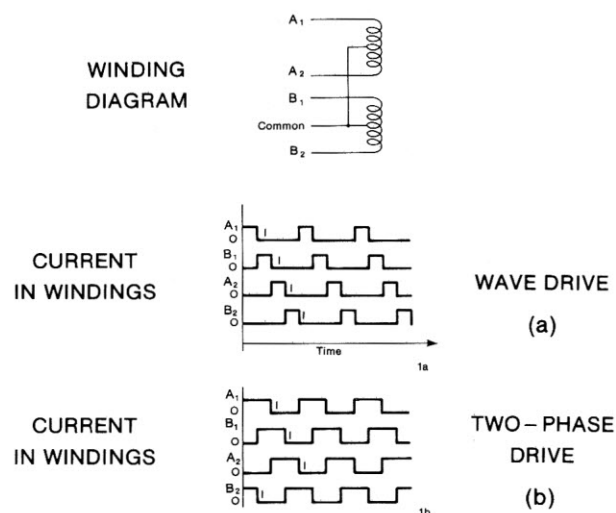


Figure 1. The basic sequences for pulsing the stator windings of a stepping motor. When the plot for a particular winding is high, the winding is energized.

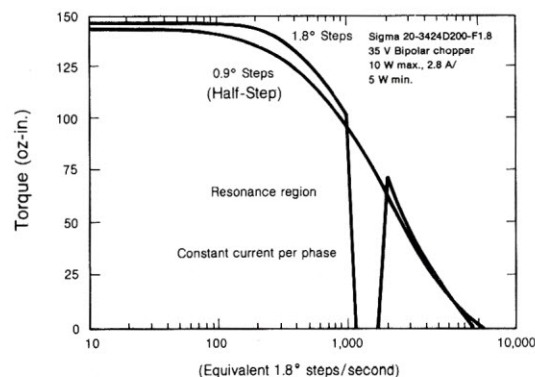


Figure 2. Torque output comparison between two-phase and half-step drive. With two-phase drive, torque drops when the step rate approaches the mechanical resonance frequency of the motor. Since half-stepping produces a more uniform drive sequence, the problem is avoided.

Power Drive Circuitry

The function of the power drive circuit for the stepping motor is twofold: it should provide a high voltage to produce a fast rise-time on the current pulse to the winding, and then it should drop the voltage to sustain the current at the correct level for the duration of the pulse. Drive requirements for steppers vary from a few volts at 50ma or so to over 100 volts at 20 amps. The shape of the current pulse affects the torque curve of the motor—a slow rise time will limit the torque available at higher speeds. The windings behave as an inductance in series with a resistance, with a time constant typically on the order of 10ms. Clearly, the higher the initial voltage, the faster the rise-time, yielding better high-speed performance (up to practical limits). It is not unusual for the starting voltage of the pulse to be 30 times the steady-state voltage.

There are several methods of power conditioning to produce the current pulse in the stator winding. The simplest and least expensive is to limit the steady-state current with a resistor, as shown in Figure 3a. Although this is the simplest and least expensive method, it fails by a wide margin to yield the maximum torque at high speeds, since the resistor increases the current rise-time. It also wastes considerable energy as heat in the resistors.

High-efficiency drives offer dramatic improvements in stepping motor performance—but at the expense of complexity and cost. A good example of such a drive is "chopper" current limiting, shown in Figure 3b. Full power supply voltage is applied at the start of a step, until the current builds up. Then, the control circuit starts switching the voltage applied across the winding off and on. The inductance of the winding filters the voltage pulses to an average DC level, producing the desired steady-state current.

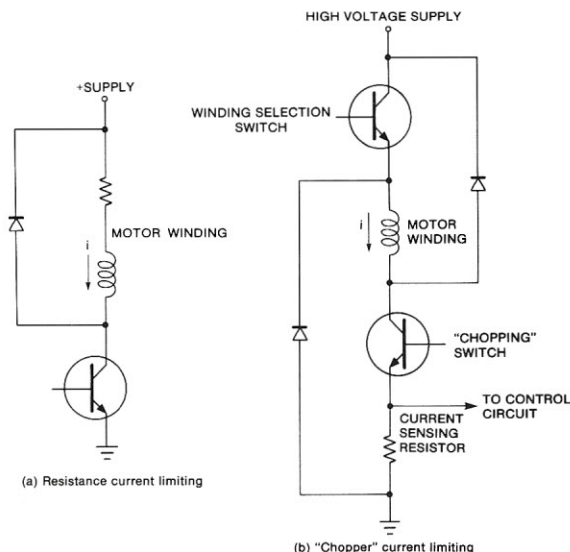


Figure 3. Two types of stepping motor power drive circuits. Resistance current limiting (a) is simplest, but wastes energy in the resistor. In a "chopper" driver (b), current is limited by pulse width modulation. (PWM).

Another high-efficiency scheme involves switching between two power supplies: one high enough to give a good rise time and a low voltage one to sustain the current. A fourth method uses a switched current source that will maintain the correct current almost regardless of the stepping rate.

The peak stepping rate we needed in our experiments was 1000Hz (full steps), which would produce a platform

speed of 5 in/sec. At this rate, the torque loading of the motor was well within the capabilities of a resistance-limited drive scheme. Since our main goal was to experiment with the software for preview control, we decided to keep things simple and use that method, with a 24V power supply as the source. (See "A Homebuilt Computer-Controlled Lathe" for a working circuit—ed.)

Mechanical Design

We built the structure of the welding positioner out of surplus aluminum stock. It stands 6' high with a base of 8' x 5'. The total welding area is about 17 sq. feet. So far, we've only automated two of the machine's six axes. Each of the two axes runs on linear bearings mounted on case-hardened steel rails. We used surplus stepping motors with 200 steps/revolution and 200 oz.-in. torque. The motors position the welding carriage along each axis by turning a lead screw, which has ball-bearing couplings on the carriage (a "ball-screw" design). A full step of the motor will move the carriage 5 mils (.005"), and half-stepping gives 2.5 mil resolution. Figure 4 shows a diagram of the welding positioner.

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FEATURES

Stepper Motor 101-SM

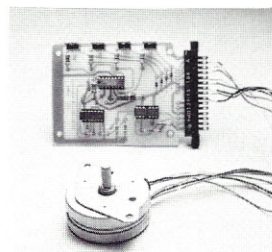
(N.A. Philips K82701 P2)	
Operating Voltage	12 VDC
Weight	8 oz
Holding Torque	10.5 oz-in
Rotation	7.5° per step
Max. Running Rate	850 steps/sec
Step Angle Tolerance	±0.5° (non cumulative)

Driver Board 2003-DB

Dimensions	4.5" x 3.2" x 0.83"
Power Requirements	9.5 18 VDC
Digital Inputs	4 20 VDC
Max. Current per winding	2 amps
Driver Chip	SAA 1027
Optically isolated	

Linear Actuator Stepper Motor

501-AM (N.A. Philips L92121 P2)	
Operating Voltage	12 VDC
Weight	1.5 oz
Max. Force Exerted (energized)	21 oz
Min. Holding Force (unenergized)	40 oz
Travel	0.002" per step
Max. travel	1.88"
Max. Pull in Rate	425 steps/sec
Max. Pull-out Rate	650 steps/sec



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101-SM	\$28.95
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2003-DB	\$44.95 (includes edge connector and heat sinks)
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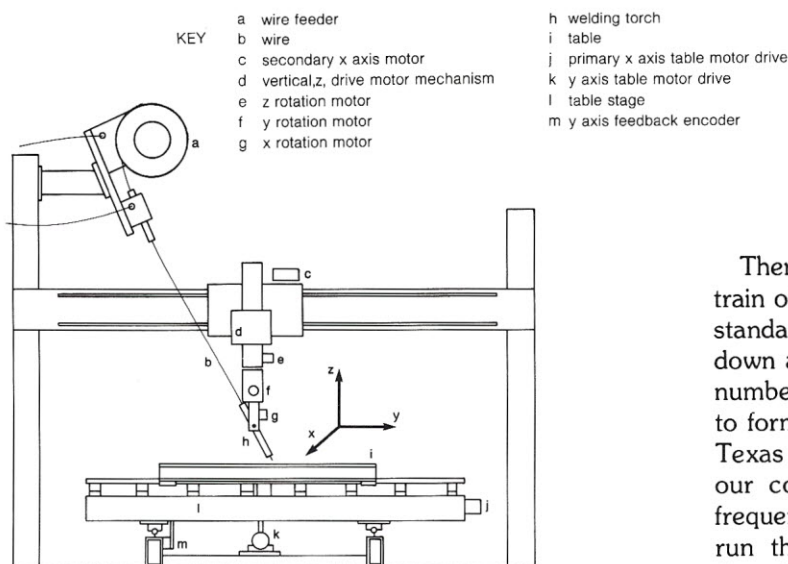


Figure 4. The six-axis arc welding positioner.

Even though it is possible to drive the steppers in slewing mode without position feedback, we decided that a closed-loop system would allow for far greater flexibility in our experiments. Having position feedback makes it easier to evaluate the performance of the controller, since the computer can detect missed steps by comparing the carriage location with the actual value. In the case of industrial processes such as arc welding, feedback may be essential for dealing with unpredictable variations in loading and with collisions. We elected to use a linear incremental optical encoder on each axis, running the entire length of travel. Although a linear encoder is more expensive than a rotary shaft encoder, it is not subject to the errors caused by "backlash" in the ball screw drive. The encoder provides standard quadrature pulse outputs that are translated into up/down position count signals by a logic circuit. (See "Using Optical Shaft Encoders" in the Fall '80 issue of *ROBOTICS AGE*—ed.)

At the end of each axis we mounted limit switches that were wired into the stepping logic as failsafes. To provide for unusual failures, we also put mechanical dead stops at the extreme ends of each axis. To protect the steel rails, position encoders, and wiring from weld spatter, we attached spring-tensioned polyvinyl covers over each axis. Although large molten drops can burn through, these covers offer adequate shielding for normal operation. Figure 5 shows a photograph of the welder.

Digital to Pulse-Train Conversion

In keeping with our decision not to burden the CPU with low-level logic functions that could be done in hardware, we decided upon using a logic circuit to convert from a digital pulse rate command to the pulse train that would drive the sequencing logic. We also wanted to have a manual joystick controller that would be able to drive the xy table at varying speeds.

There are two convenient ways of generating a pulse train of variable frequency. One is entirely digital, using a standard TTL rate multiplier chip. The 74LS97 will scale down a reference clock in proportion to the 6 bit binary number on its input pins. You can cascade several of them to form an n bit rate multiplier. The *TTL Data Book* by Texas Instruments shows how. To use this approach in our controller, we could have a built a clock with a frequency equal to our maximum stepping rate and then run the latched output lines from a parallel interface directly to the multiplier. Its output could drive the sequencing logic directly.

We used a different method, however—one that made adding the joystick controller quite simple. Instead of scaling the pulse rate digitally, we used a digital-to-analog (DAC) converter to produce a voltage proportional to our 8 bit pulse rate command and then used that voltage as the input to a voltage controlled oscillator (VCO). Although this approach lacks the inherent accuracy of a purely digital circuit, the error in the output pulse frequency was at most a few percent—entirely adequate for our experiments. Figure 6 shows the circuit that converts the analog voltage from the DAC or joystick to the stepping pulses. A DAC input of 0FF(hex) produces a 2000Hz pulse train. The addition of a simple switching circuit (Figure 7) let us select between manual or computer control of the platform.

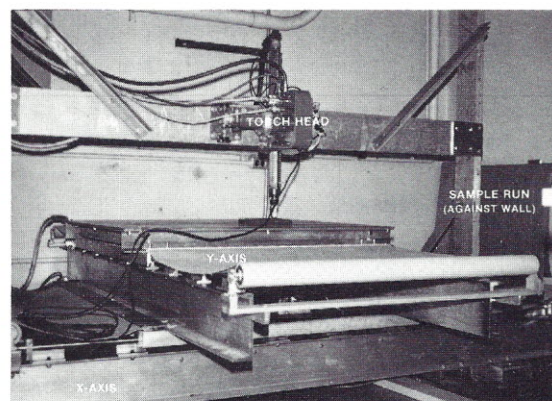


Figure 5. Photo of the welder. Vinyl covers are stretched over the carriage and kept taut by window-shade springs.

Electrical noise can be a severe problem for circuitry anywhere near an arc welder. In an earlier arc welding project, lines from the optical encoder picked up radio frequency interference (RFI) from the welder that showed up as extra pulses. This threw off the controller's position

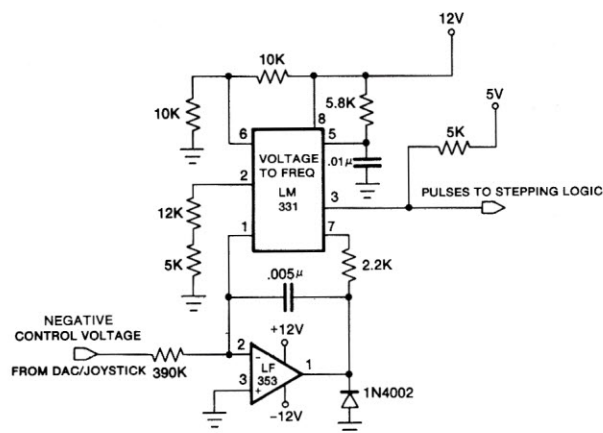


Figure 6. Circuit for generating a pulse train with frequency proportional to an analog voltage.

feedback measurements and caused poor performance. Output lines from the interface can be affected too. We used optical isolators and shielding on all I/O lines on the interface. Figure 8 shows the Hewlett-Packard HP2630 opto-isolator circuit, which has a throughput near 1MHz.

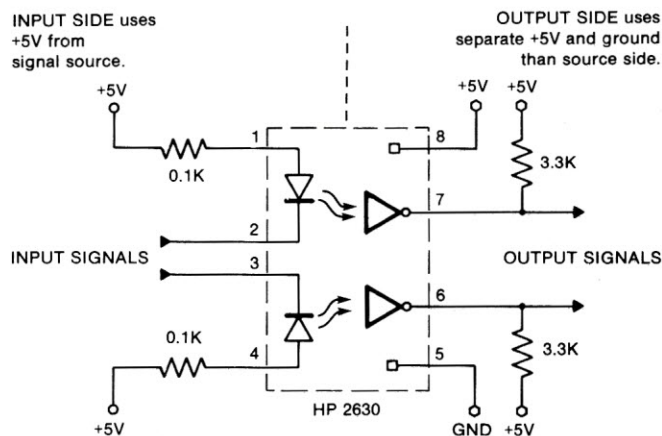


Figure 8. Optical isolation circuit used on interface lines.

The Control Software

The computer we used to control the system was an LSI-11 system by Digital Equipment Corp. With only FORTRAN, BASIC, and assembly language available as the source language for the control software, we picked FORTRAN. Interpreted BASIC would have been too slow to perform the preview control calculations in real time, and assembly language would have taken too much coding and debugging. DEC FORTRAN has "Ipeek" and "Ipoke" commands for direct access to the I/O ports, as well as provisions for handling interrupts for real-time control, so we could use it for the entire system.

Part I gave a description of the Preview Path Control scheme we used to calculate the pulse rate commands to be sent to the stepping motor control logic. As described

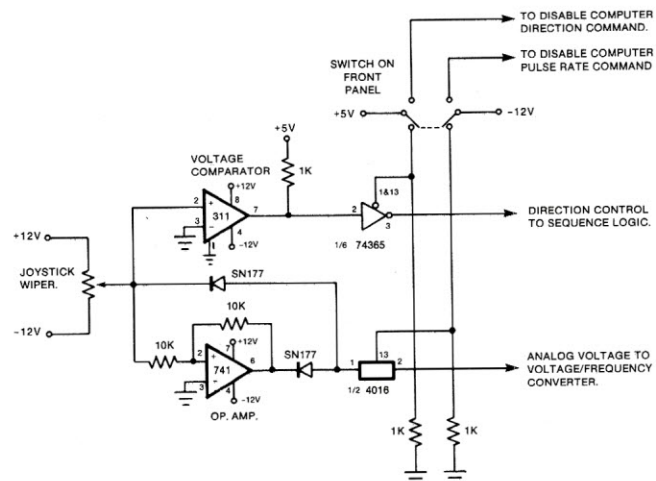


Figure 7. Circuit for switching between joystick controller and computer. The 741 op-amp inverts the joystick voltage and the two diodes insure that only the negated absolute value of the joystick voltage is applied to the 4016 CMOS analog switch.

in Part I, the basic operations in this procedure are as follows. For each axis: (1) Determine the component of position error along the axis. We used a representation of the desired path stored in memory and the position feedback from the encoders. (2.) Compute the "feed-forward" term from the preview information. Here we used the stored path again, but measurements from a seam tracking sensor would be used if available. (3) Update the integral error term. (4) Multiply each term by its "gain" and sum the results to get the "ideal" stepping rate command for the axis. (5) Modify the command if necessary and replace the old rate command (and direction, if necessary) in the output latches for the axis.

These operations are repeated at a fixed rate, determined by the *cycle time* of the control loop. The LSI-11 has a 60Hz clock interrupt, which the program "divides down" by counting interrupts. We normally used a divisor of 6—every 6 interrupts, the program would repeat the control calculations. Interrupts may occur and be counted during the calculations, which must, of course, be completed before the 6th interrupt occurs. This cycle time is the key to setting the gain terms used in the calculations. The "steady-state" gain of the system must be high enough so that the controller could correct some maximum position error within one cycle. Initial choices for the various gains can be derived analytically (see [1]). In practice, however, these terms are adjusted to get the best performance.

Step 5 of the cycle, modifying the ideal rate command, requires knowing the torque and load characteristics of the system. Comparing the new rate with the old gives the acceleration during the next interval. If, given the inertia and friction of the load, this acceleration would require a torque greater than the maximum available from the motor at the current stepping rate, the controller must



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reduce the new rate appropriately. We experimentally determined all the factors necessary to perform this acceleration limiting—the computation reduces to little more than a few simple conditional assignment statements in the real-time loop. With our closed-loop system, we could afford to make some approximations. An open-loop system would need a fairly detailed model to get the most from the motors and still be sure that they won't miss steps.

With the exception of some floating point calculations to simulate the effects of random noise from a seam-tracking sensor (see part I), we did all the calculations in integer arithmetic for maximum speed. With the random noise, the controller required 14ms for all the computations in the cycle. Without it, it needed only 11.4ms. Thus, the control calculations required only 11.4% of the LSI-11's compute power, based on the 100ms control cycle time we normally used.

The rest of the time could be spent processing signals from a seam-tracking sensor or controlling the other axes of the robot when they are added.

Performance of the System

Over 85% of the time we devoted to this project was spent on designing, building, and debugging the hardware. Developing the control algorithm took about 5%, and the rest went towards writing and debugging the software.

Much of the hardware development time was consumed dealing with RF noise problems from the arc welder. The first time we turned on the welder, it destroyed a flip-flop in the motor sequencing logic. The long lines from the limit switches, which were wired into the logic as fail-safes, apparently acted as antennas, picking up RFI. We added opto-isolators to these lines and shielded them, like the lines between the computer interface and the control logic. The welder also caused large transients in the AC power lines. We added AC line filters, shielded the cable from the welding power supply to the torch, and isolated the welder's ground. All this cleared up most of the problems. Adding additional filter capacitors to the sequencing logic helped.

If we were designing the hardware over again, we would definitely use one of the stepping motor control ICs now commercially available. Sigma Instruments of Braintree,

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CIRCLE 20

Mass. has a chip that will perform most of the sequencing logic functions. A more expensive chip by Cybernetic Micro Systems of Los Altos, California functions as a complete motor control computer. You can program it for half- or full-stepping, set the stepping rate and acceleration numerically, and perform numerous other functions. It will control the drive circuits directly.

As we showed in the run-time plots in Part I, the Preview Control method proved quite satisfactory for continuous-path control of stepping motors. We are still working to improve the system, and we plan to add four more stepper-driven axes to the welding positioner by the end of the year. We are also continuing our research in the area of adaptively controlling the welding parameters (arc power, speed, and weaving), in addition to the welding path, based on signals from arc sensors and from advanced seam-tracking sensors. ®

References

- [1] Shafi Motiwala, "Design, Development and Implementation of a Preview Control Scheme for On-Line Seam Tracking for Welding Automation," MS Thesis, Dept. of Mechanical Eng., U. California, Berkeley, Dec. 5, 1980.
- [2] B.C. Kuo, *Theory and Application of Step Motors*, West Publishing Co., 1974.

BUILD A LOW-COST IMAGE DIGITIZER

Would you believe that you can build a complete image digitizer for only about five dollars in parts? Well, you can—provided that you have Radio Shack's new TRS-80 Color Computer or some other micro with the same useful features. This machine makes it easy to get started in robotics experimentation. It comes with two 6 bit digital-to-analog converters (DACs) and four analog-to-digital converter (ADC) channels. Also included are a serial communications port, a 40 pin connector that brings out all the bus signals of the 6809 CPU, built-in cassette I/O, and, of course, its color graphics capability: 12 different colors with resolution up to 192×256 picture elements (pixels). All this, with an extended BASIC interpreter, in a package small enough to mount as a single board computer inside a robot. I'll be writing about that latter application in a future article. But for now, I'll show you how I used the Color Computer to get started with image processing for robot vision.

The Image Sensor

The key to this low-cost digitizer lies in using one of the Color Computer's joysticks as a pointing device. On the end of the joystick's handle, I mounted a Radio Shack solar cigarette lighter, which is a small parabolic reflector with a fixture at its focal point. To this fixture I bonded a CdS photocell (Radio Shack part #276-116) with Superglue, so that the light collected by the mirror is focused on the photocell's surface. The digitizer operates by reading the photocell output and the joystick location as you manually move the joystick in a scanning pattern. For use in a robot, of course, you would want to replace the manually positioned joystick by some form of automatic pointer, but this simple trick lets you work on robot vision software—using real images—with the barest minimum of hardware. Figure 1 shows the sensor assembly mounted on the joystick.

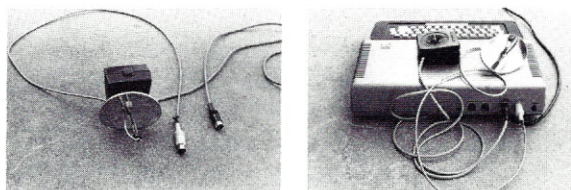


Figure 1. The reflector and photocell are mounted on the end of one of the Color Computer's joysticks.

The cadmium sulphide photocell is sensitive to light through the entire visible spectrum, with a response curve as shown in Figure 2. It is a resistive type photocell—varying from 500K ohms in the dark, to 1.7K ohms in one foot-candle (ftc.) illumination, down to 100 ohms at 100 ftc. The size of this particular photocell and the geometry of the mirror resulted in a field of view approximately 1.5 degrees wide. A smaller photocell could give a higher resolution. But since the computer can only resolve the joystick position to within a degree or so, this arrangement was satisfactory for my experiments.

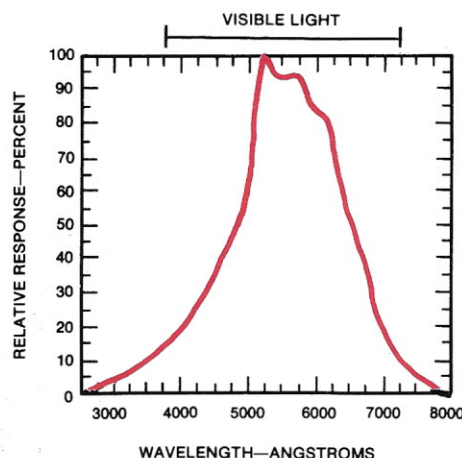


Figure 2. The relative response curve of the CdS photocell.

Interfacing the Sensor to the ADC

Each joystick on the TRS-80 CC contains two potentiometers that read its position in two dimensions (degrees of freedom). Figure 3 shows the schematic of a joystick and its connector. Pin 5 provides 5V to power the divider, and pins 1 and 2 lead to a pair of ADC channels in the computer. As you move the joystick, the voltages on pins 1 and 2 vary in the range from 0 to 5V. Pin 4 is grounded by the push button "fire" switch on the joystick. I used the right joystick to point the sensor.

The Color Computer performs A/D conversion by a built-in BASIC intrinsic subroutine, called JOYSTK, that uses the two DACs. It accesses each DAC by writing a number in the six most significant bits of its memory location. The 6 bit value (0-63) is latched and converted to an analog voltage between .25V and 4.75V (by a resistor ladder type of converter). To perform an A/D conversion, one of the analog channels is selected by an analog switch and compared with the DAC output by an analog comparator. Each DAC has two such channels that can be selected for conversion. The intrinsic software varies the DAC output until the voltages match, then returns the corresponding 6 bit number. A call to JOYSTK requires a little over 4ms.

To sense the light on the photocell, I used a simple resistor divider to convert the cell's change in resistance to a voltage in the 0-5V range used by the joysticks. This let me use the port for the unused left joystick as the input port for the image sensor. The joystick port also supplies the 5V, as shown in Figure 4. I used coaxial cable to bring the signal back from the photocell, minimizing noise due to RF interference, etc. The 10K pot, used to adjust the sensitivity of the sensor, is bonded directly to the DIN plug at the joystick connector. The sensor output is connected to pin 1 of the plug—JOYSTK(2) reads the voltage on this pin.

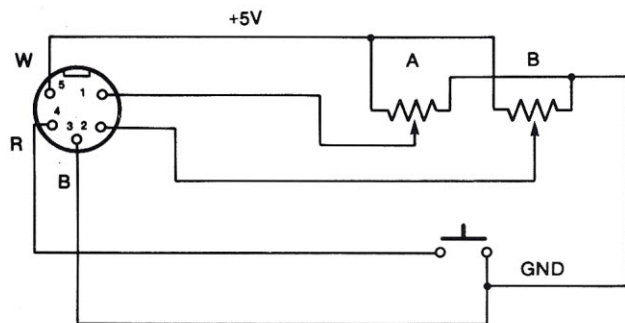


Figure 3. Joystick schematic.

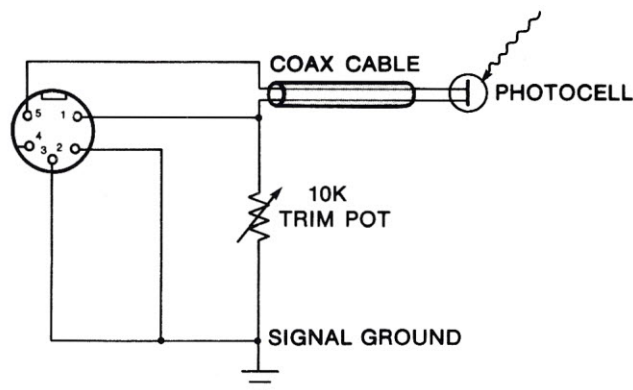


Figure 4. Photocell interface schematic.

Using the Sensor

There are a number of ways you can use the output of this simple sensor. Since the computer can read the pointing angles of the joystick, it doesn't depend on the accuracy of your manual scan. It can use the two joystick position values as an array index and store the digitized value at the right "coordinates" in the image. As a demonstration program, I used the sensor readings to form a "false color" image which I displayed using the machine's color graphics.

Figure 5 gives the listing of this program. The range of values returned by the sensor is partitioned into four bands, each displayed as a different color. the resolution of the display varies depending upon the color mode you select. In the four-color mode I used in the program the display has 192x256 pixels. I scaled up the joystick readings to fill the TV screen. Scale factors of 4 and 3 for the horizontal and vertical display coordinates, respectively, gave a reasonably undistorted "mapping" from joystick to screen coordinates. the PAINT statement fills in the boundary created by the CIRCLE statement in a particular color.

The program will continue to refresh the image as long as you keep scanning the sensor, with new colors painting over old if the image varies. Figure 6 shows a "false color" image of a light bulb.

By storing image values in an array, you can begin to do true image processing. You can write programs that scan the stored image to find light sources or to perform other vision operations. As you try to make effective use of this rich source of information, you will quickly find out that sight is an incredibly complex sense. This simple sensor

will let you start exploring robot vision—without expensive TV cameras and complex video interfacing. 

```

20 ' LOW COST IMAGE DIGITIZER PROGRAM
30 ' BY
40 ' DON MCALLISTER
50 '
80 ' SET COLOR MODE FOR (192x256) 4 COLOR MODE
90 PMODE 3,1
100 ' CLEAR HIGH RESOLUTION SCREEN
110 PCLS
120 SCREEN 1,1
130 ' READ RIGHT JOYSTICK INPUTS
140 J0=JOYSTK(0)
150 J1=JOYSTK (1)
160 ' READ PHOTOCELL OUTPUT (J2)
170 J2=JOYSTK (2)
180 J3=JOYSTK (3)
190 ' IF PHOTOCELL OUTPUT > 50 SET COLOR = ORANGE
200 IF J2>50 THEN C=0
210 ' IF PHOTOCELL OUTPUT < 50 AND > 30 SET COLOR = BLUE
220 IF J2<50 AND J2>30 THEN C=3
230 ' IF PHOTOCELL OUTPUT < 30 AND > 20 SET COLOR = GREEN
240 IF J2<30 AND J2>20 THEN C=2
250 ' IF PHOTOCELL OUTPUT < 20 SET COLOR = BACKGROUND (WHITE)
260 IF J2<20 THEN C=1
270 ' SCALE HORIZONTAL AND VERTICAL AXES
280 ' FOR RIGHT JOYSTICK OUTPUT
290 X=J0*4
300 Y=J1*3
310 ' DRAW CIRCLE AROUND RIGHT JOYSTICK COORDINATES
320 ' WITH FALSE COLOR = C, AND RADIUS 4 PIXELS
330 CIRCLE (X,Y),4,C
340 ' COLOR INTERIOR OF CIRCLE WITH COLOR = C
350 PAINT (X,Y), C
360 ' RETURN TO SAMPLE PHOTOCELL OUTPUT
370 GOTO 140
380 END

```

Figure 5. False color image display program.

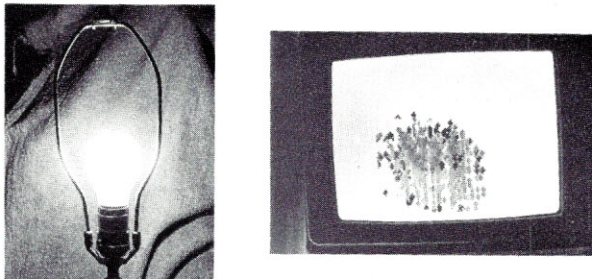


Figure 6. Image generated by scanning a light fixture.

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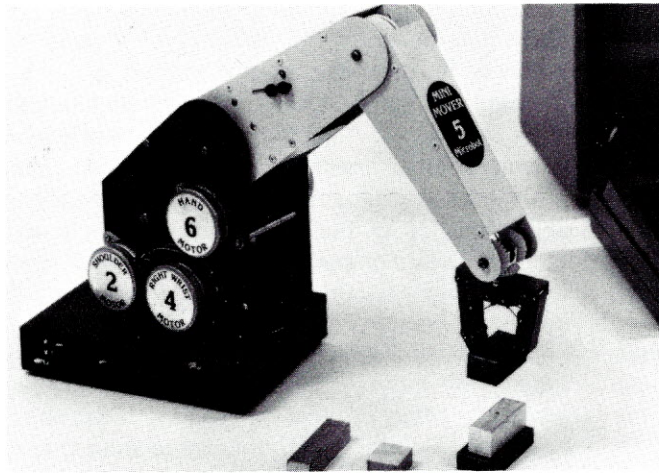
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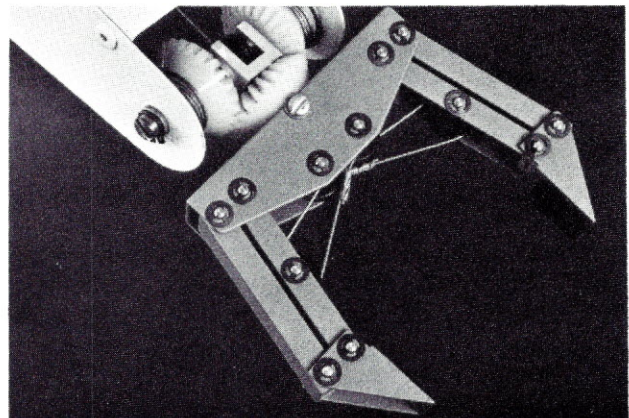
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Report from JACC-81

by Alan Thompson

This June, *Robotics Age* covered the 1981 Joint Automatic Control Conference, held at the University of Virginia. The JACC is one of the few scientific conferences that includes sessions on advanced robotics research. The conference covers a wide variety of topics in control systems design: aerospace, manufacturing and energy processes, analytic methods—in addition to robotics. The term “joint” refers to the sponsorship of the conference by four different professional societies: AICE, ASME, IEEE, and the ISA.

One of the plenary sessions was addressed by Phillippe Villers, president of Automatrix, Inc. Villers spoke on “Robotics as a Computer Controlled System,” and informed the gathering of the trend in industrial robotics towards increasingly intelligent robots, including many with advanced sensory systems.

Three of the conference’s 45 technical sessions were devoted to robotics. I’ll give a brief synopsis of some of the papers presented.

Wayne Book and David Ruis spoke on the “Control of a Robotic Exercise Machine.” This robot is a two-axis hydraulic machine designed to follow a path in a plane in response to force applied by a human. The subject teaches the machine the path he would like to follow and the resistance it should apply. This means that the robot can provide high resistance throughout the range of motion of any isolated muscle group, creating ideal exercise conditions.

In “Heuristic Position Control of a Multi-Link Manipulator,” S. Chand and Keith Doty of Univ. Florida, Gainesville described their method of controlling a multi-link robot arm without a complex mathematical model. They divide the working space of the arm into three regions, each associated with a fixed position of the first few axes. The joint angles of the remaining “free” axes are found by table lookup, indexed by the target distance.

In the same session, your correspondent spoke on “Steps Toward Practical Robot Planning.” This paper dealt with the prospects for applying advanced techniques from Artificial Intelligence research to practical problems in industrial robotics. With increasingly complex robot systems, the application of AI reasoning systems could significantly simplify the job of applying such robots to industrial tasks. A brief survey of recent research developments indicates that the major problem is the integration and human engineering of some of these generic AI systems. The solution could produce some truly useful software tools for developing robot applications.

An important software tool to aid in the design of a new robot manipulator is a *simulator*—a program that will

accurately describe the behavior of a given robot arm geometry in response to joint torques or forces. M. W. Walker and D. E. Orin described such a program in “Efficient Dynamic Computer Simulation of Robotic Mechanisms.” They presented four different methods for obtaining the joint accelerations given the initial positions and velocities of the joints and the forces or torques applied. They compared the complexity of the methods and the execution times of the programs that used them.

Tomas Lozano-Perez of MIT presented a paper on “Spatial Reasoning in the Planning of Robot Motions.” The paper dealt with the class of problems that involve finding where to place or how to move a solid object in the presence of obstacles. The ability to solve these kinds of problems is essential to the automatic planning of robot motions—that is, giving a robot the ability to plan how to grasp a part and place it at some destination without hitting an obstacle. The paper describes an algorithm that will plan safe pick and place motions for a Cartesian manipulator, using a 3D geometric model of the workspace.

“Visual Tracking in Stereo,” by Eric Saund, Don Gennery, and Robert Cunningham of JPL, describes a method for tracking moving targets using two TV cameras and special image processing hardware. Using edge evidence provided by the hardware, the tracking software maintains an internal model of the location, orientation, and velocity of the object in 3D space. It uses this model to predict where features of the object will appear in the (2D) images produced by the TV cameras. The differences in the locations of the features are used to update the model.

To control a robot manipulator accurately at high speeds, it is essential to counteract the effects of the inertial forces caused by the arm’s motion—the centrifugal and coriolis forces. One way of doing this is to use a complete mathematical model of the equations of motion of the arm—a collection of equations that can grow quite complex due to the various interactions between the links. Recently, two differing formulations of these equations were proposed that offered efficient solutions for robot control: the “iterative Newton-Euler” approach developed at Purdue and the “recursive Lagrangian” formulation developed at MIT. In his paper, “On the Equivalence of Lagrangian and Newton-Euler Dynamics for Manipulators,” William Silver of MIT compares these methods and shows that they in fact reduce to equivalent computations.

Another approach to robot control is to enable the controller to “learn” how to compensate for nonlinearities in the arm’s dynamic equations and for unknown payload characteristics. This approach is called *adaptive control*.

Steven Dubowsky of UCLA presented a paper entitled, "On the Adaptive Control of Robotic Manipulators: The Discrete-Time Case." In this paper he describes a method of adaptive control suitable for use in a microcomputer controlled robot. He applied this method of adaptive control suitable for use in a microcomputer controlled robot. He applied this method to a robot controlled by a SYM-1 microcomputer, which uses a 6502 CPU.

John Craig and Kenneth Salisbury of Stanford presented the design of a new three-fingered robot hand and its controller in "Articulated Hands: Force Control and Kinematic Issues." They based their design on an extensive geometrical analysis of the act of grasping, using a simulator program to optimize the placement of the fingers and the dimensions of their segments. Next, they designed a hybrid controller that combines both position and contact force control. It allows the behavior of the hand to be described in an external Cartesian coordinate frame instead of in terms of the knuckle angles. The controller gets its force feedback from sensors mounted on the cable "tendons" that move the knuckles, measuring cable tension directly.

JACC-81 gave us plenty of evidence that the field of Robotics is progressing at a dramatic pace. Look for more examples of this in our upcoming reports on the International Joint Conference on Artificial Intelligence (IJCAI), held in August, and on the International Symposium on Industrial Robots (ISIR), to be held this October in Tokyo.

The American Robotics Society

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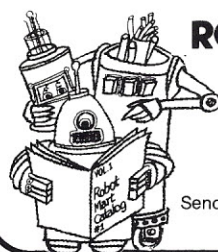
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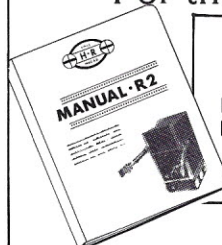
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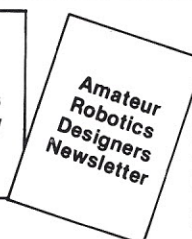
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CIRCLE 15

The Robot Builder's Bookshelf

by David Smith and
Mike Schoonmaker, III

Many of our readers have asked us to print a reading list of books that will provide a broad and thorough background in robotics and artificial intelligence (AI). Readers Smith and Schoonmaker have given us a good start with this annotated listing. We will be supplementing the list from time to time.

We start our list with two books that offer constructive criticism of AI:

What Computers Can't Do: The Limits of Artificial Intelligence, by Hubert L. Dreyfus, Harper Colophon Books, Harper and Row, Publishers, New York, NY (1972). This book is not about robots but covers the problems and progress of artificial intelligence in general.

Computer Power and Human Reason (From Judgement to Calculation), by Joseph Weizenbaum. W. H. Freeman.

Weizenbaum argues that computers will never achieve true intelligence. They will only be able to mimic behavior that humans will interpret as intelligent. He also argues that building such systems could be dangerous.

The following books are about building your own robot:

How to Build Your Own Self-Programming Robot, by David L. Heiserman, Tab Books, Blue Ridge Summit, PA 17214 (1979).

The robot in this book uses an 8085 microprocessor in a wire-wrapped, on-board system. It has no hands or arms. It senses obstacles by checking if the motors have stalled. Not recommended for a room full of breakables!

Build Your Own Working Robot, by David L. Heiserman, Tab Books.

This robot does not use a microprocessor. The "brain" is built up out of separate TTL logic chips, and it has no hands or arms. The robot uses bumpers with switches for object contact sensing.

Robot Intelligence...With Experiments, by David L. Heiserman, Tab Books (1981).

This is the book for those who want to experiment with robotic software without spending money on a robot body. David Heiserman wrote a series of programs in Level II basic for a TRS-80 with 4K of memory. The "robot" is a graphics figure that wanders around on the screen. No disk drive is required and the standard screen is used.

How to Build Your Own Working Robot Pet, by Frank DaCosta, Tab Books.

DaCosta shows how to make a robot "dog." It has no hands or arms and features an on board wire-wrap system using the 8085 CPU. Obstacle detection is done with ultrasonics and bumper contact switches.

Android Design, by Martin Bradley Weinstein, Hayden Book Company, Inc., 50 Essex St., Rochelle Park, NJ 07662 (1981).

There is no other book on the market that has as much solid information as this one. It has over 90 addresses of parts suppliers. It shows how to make a very flexible finger out of bike chain. It shows how to make a 64 by 64 solid-state TV camera out of a dynamic ram chip. It includes information on VMOS FET speed and direction controls for DC motors. It covers a triangular wheel subsystem that can climb stairs.

(Editors note: *ROBOTICS AGE* plans to feature an in-depth review of this book in an upcoming issue.)

Computers That Talk, by George Papcun and Lloyd Rice, Byte/McGraw-Hill, \$18.95 (available winter 1982).

Get your robot to talk. If only it was as easy to get it to hear.

How to build a Computer-Controlled Robot, by Tod Loofbourrow, Hayden Book Company, Inc. (1978).

Ultrasonics and bumper contact switches do obstacle detection. This is the book to read if you don't want to build the CPU "brain." The robot, "Mike," uses an on-board KIM (6502) with a memory expansion unit. One problem: the KIM is a little out of date. Take a look at the AIM, SYM, VIM, or SuperKIM. Even so, Loofbourrow gives solid technical information in a lucid presentation.

The next books provide general information related to robotics and AI:

The Brains of Men and Machines, by Ernest W. Kent, Byte/McGraw-Hill, \$15.95.

Kent gives computer-like models for human intelligence and argues how human intelligence may influence computer design.

Brains, Behavior, and Robotics, by James S. Albus, Byte/McGraw-Hill, \$15.95, (1981).

Albus takes a look at how the human brain works and gives design considerations in building a robot brain.

Handbook of Remote Control and Automation Techniques, by John E. Cunningham, Tab Books (1978).

A general look at making objects move. It contains some information on DC motors, hydraulics, electronics and control systems.

Human Factors Applications in Teleoperator Design and Operation, by Edwin G. Johnsen and William R. Corliss, Wiley-Interscience, A division of John Wiley & Sons, Inc., New York, (1971).

Johnsen and Corliss discuss robot arms, hands, and the senses. The bibliography is a gold mine of information.

Computers and Thought, by Edward A. Feigenbaum and Julian Feldman, McGraw-Hill, (1963) \$12.50.

This is a well-organized collection of 28 papers by experts in the field. It gives a good background in artificial intelligence.

Introduction to Artificial Intelligence, by Philip C. Jackson, Petrocelli/Charter (1974).

This book emphasizes the GPS system and heuristic search theory. It also includes game trees, pattern perception, theorem proving, and semantic information processing.

The Thinking Computer, Mind Inside Matter, by Bertram Raphael, W. H. Freeman (1976), paperback. This is probably one of the most readable introductions to AI, and a bargain at \$6.95.

A.I.—The Heuristic Programming Approach, by James R. Slagle, McGraw-Hill (1971).

The Relevance of General Systems Theory, by Ervin Laszlo, George Braziller, N. Y. (1972). Many people think systems theory is

important to robotics. I have my own system. If it doesn't work, use a hammer. If it does work, use a hammer. I found this book interesting.

Cybernetics, by F. H. George, Dover (1971).

Cybernetics is dated as a word, but this is still a reasonable introductory text.

The Complete Strategist, by J. D. Williams, McGraw-Hill, (Revised Copyright by the Rand Corp. 1966). This is recommended reading for anyone interested in games. It is very readable, illustrating all techniques covered in the text. Economic game theory is not covered.

Cybernetic Frontiers, by Stewart Brand, Random House (1974). Though entertaining, this book is non-technical and rather dated.

Great Ideas in Information Theory (Language and Cybernetics), by Jagjit Singh, Dover (1966). Singh gives a good history of the early work in AI. It is very readable.

Man and the Computer, by John G. Kemeny, Chas. Scribner and Sons (1972).

This book explains the symbiosis of man and the computer. Next he should do a book on the symbiosis of man and the A.I. device.

Great Ideas in Operations Research, by Jagjit Singh, Dover (1968).

Operations Research is problem solving by mathematics to seek optimal solutions.

The Psychology of Thinking, by Robert Thomson, Pelican (1957-1967).

A well documented book that admits it knows nothing. Reprinted again and again.

IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE, New York (1979). Recommended reading.

Essentials of Statistics for Scientists and Technologists, by C. Mack, Plenum Publishing Co., 227 West 17th St., NY 10011.

A book on statistics for someone who wants to build robots? Yes, I think you'll find statistics useful in evaluating the performance of your robot. This book is very readable and is the best one I have found so far.

Electronics books for robot builders:

TTL Cookbook, by Don Lancaster, Howard W. Sams & Co., 4300 West 62nd St., Indianapolis, Ind. 46268 (1964).

Lancaster describes the operation and function of the most common chips. He also gives some valuable hints on construction.

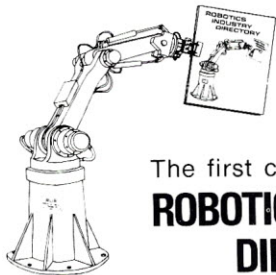
CMOS Cookbook, by Don Lancaster, Howard W. Sams & Co. (1977).

CMOS uses less power than TTL, which is important when you see the drain that the CPU puts on a robot's batteries. The TTL Cookbook and the CMOS Cookbook both cover about the same material, but using the different logic families.

Engineer's Notebook, Integrated Circuit Applications, by Forrest M. Mims, III, Radio Shack (1979).

Mims presents a collection of circuits that use Radio Shack parts. It would be helpful to someone learning electronics.

(continued on page 45)



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Article

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- 2 Edge Detection in Man and Machine
- 3 Continuous Path Control with Stepping Motors
- 4 Build a Low-Cost Image Digitizer
- 5 Report from JACC-81
- 6 The Robot Builder's Bookshelf

Eye to Industry

by Jerry W. Saveriano

You might want to start shopping for Susan Calvin's birthday present. She will be born in 1982—at least according to Isaac Asimov's collection of stories *I, Robot*. In these tales, Calvin is the first great Robopsychologist." She is the woman behind the machines, one of the masterminds who run "United States Robots and Mechanical Men."

In real life, a man named Peter Chance stands behind **United States Robots**. He admits naming the firm after Asimov's fictional company. But there is nothing fictional about the \$2.2 million in private investment capital that Chance raised through an offering with **Wertheim** of New York.

US Robots makes the Maker, a manipulator with four rotary axes and one linear telescoping joint. Unveiled at Robots V in 1979, the machine had all the wiggles, jiggles, and glitches you'd expect from a prototype robot. But now the bugs have been worked out, and US Robots is shipping its first production models. The first unit goes to **General Electric** in Schenectady, the second to **General Motors**, and the third to **Westinghouse**. Full production of the Maker is scheduled to begin this September.

It's a long way from the Maker's home in Pennsylvania to Sweden, where **Asea's** robot hails from. But now Asea plans to partially manufacture and assemble its robot here, in New Berlin, Wisconsin. Asea also plans to build a facility in Troy, Michigan. It will serve as a place to show their robots, train personnel, service their machines, store spare parts, and develop applications.

Asea, which claims to be Number 2 in the dollar volume of worldwide robot sales, has now expanded its product line. Recently they added the **Electrolux** point-to-point materials handling robot. Asea purchased Electrolux's industrial robot operations in Stockholm, Sweden.

The Electrolux machines are currently being sold by **Automatix** of Burlington, Massachusetts. I asked Phillip Villers, president of Automatix, whether Asea's takeover would affect his company's relationship with Electrolux. He told *Robotics Age*, "Nothing has been decided yet, and we are not very concerned because we have placed most of our efforts and resources in the development of intelligent robot systems, such as the **Hitachi** based Robovision robot welding system."

The Hitachi/Automatix system is in direct competition with Asea's welding robots, the IRb-6 and the IRb-60.

Therefore, Asea will probably not permit Automatix to carry the Electrolux robots.

On the surface, it seems like another blow to Automatix that **General Electric** recently agreed to build and sell the Hitachi robots in the US. But I believe this will not impact Automatix's good OEM relationship with Hitachi. As Villers said, "We will continue to use the Hitachi manipulator with our own controllers and in our welding systems. We also find it encouraging that a company as big as GE is following our lead in the use of vision and precision welding robots. This supports our belief in the market decisions we made early on."

Turning our eyes to the west, we see an interesting new firm in Carlsbad, California. Lawrence A. Goshorn, the man who founded **General Automation**, now heads **International Robomation/Intelligence**. Its new robot—with 5 to 7 axes, a load capacity of 50 pounds, digital air-servomotor drives, and Motorola 68000s to control each axis—costs \$9800. With these specifications, the robot looks favorable for use in machine tool loading and unloading.

Meanwhile, back in Connecticut, **Unimation** is expanding all over the lush Danbury countryside. The moves are coming so fast and furious that some employees are having difficulty finding their desks in the morning. Also—although they have not yet announced it officially—Unimation is shipping the first of the Unimates with the new VAL controller to **General Motors** in Europe. This controller is similar to the PUMA's LSI-11 controller with the VAL robot programming language.

The **US Army** may use Unimation's rival, **Cincinnati Milacron**, to supply arc welding robots. Cincinnati's T-3 robot will do arc welding on the suspensions of the army's M113-A2 armored personnel carriers. The T-3 was chosen because its articulated arm could reach the many hard-to-get positions needed on this application. If the project is funded, the army expects it to cost half a million dollars.

Another established US robot firm has gone public. **Prab Robots**, formerly Prab Conveyors, plans to offer the public 500,000 shares of common stock. The **First of Michigan Corp.** is the lead underwriter of this stock offer, whose price is said to be between \$10 and \$12 per share. Located in Kalamazoo, Michigan, Prab is the third largest robot builder in the US. The company manufactures the Prab and Versatran robots and has shown a profit every

year of its 20 year history.

There are rumors in the air... Robots VI may turn out to be one hell of a trade show, if half of those rumors are true. This much we do know: **IBM** has reserved a large booth at the show and plans to present several papers on vision and robotics. Rumor has it that IBM will take this opportunity to introduce several robot and vision products. Some of these are reportedly being built by **Jade Manufacturing** in Philadelphia. Jade builds custom machinery for IBM.

Further speculation says one of IBM's robots is a hydraulic, cartesian coordinate manipulator. I haven't been able to get IBM to comment on these rumors—but I keep trying.

GE has also reserved a large booth at Robots VI. Surely it will show its newly acquired robotic lines. **Westinghouse** and **Bendix** are also ready to throw their grippers into the robotics ring. But don't expect to see any **Texas Instruments** robots at the show. TI has dropped both their robot and bubble memory projects—at least temporarily. TI has had rough times lately, laying off thousands of workers. Rumors have it that TI is marshalling its resources behind its currently profitable products.

Ironically, as TI cuts back, **US Robots** is offering a plug-in bubble option with their Maker robot. US Robots will get their bubbles from **Fujitsu-Fanuc**, who offer bubble memory on their own General Numeric robots.

I hope these recent setbacks don't mean we won't be seeing any new robots from Texas. I know things are tough there now, but...I wonder what Susan Calvin would do?

Be Seeing You!

If you have robotics-related information that you believe is noteworthy, or have suggestions for topics for this column, please write us at *Eye to Industry*, **Robotics Age**, P. O. Box 725, La Canada, California 91011, or call 213/352-7937.

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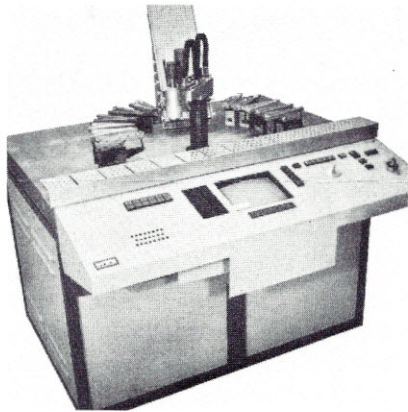
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The Microplacer allows teach-in-mode programming, automatically calculating the shortest and quickest path of travel. Programs can be stored on floppy disc.

For further information or price quotations, contact Mr. Jacques Werth, MTI Corporation, 55 Industrial Dr., Ivyland, PA, 18974. Phone 215/355-3110. **CIRCLE 1**

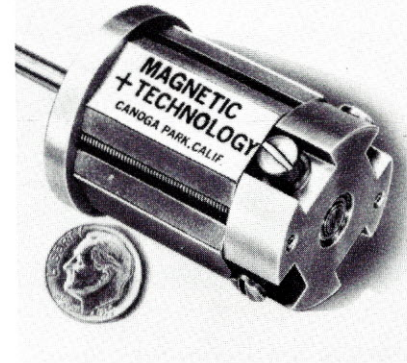
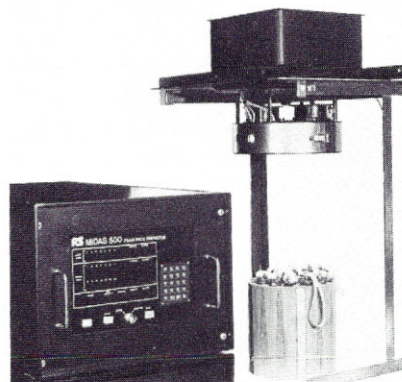
On Line Image Processor

Recognition systems Inc. announces the MIDAS 500 Production Line Image Processing System. The MIDAS 500 was designed for such applications as print pattern matching, assembly verification, and dimension measurement. The system learns the pattern to be recognized, adds tolerance zones to the standard pattern, and compares specimens under test to the learned pattern. The test specimen is accepted or rejected depending on how closely it matches the learned pattern.

The processing unit for the MIDAS 500 is a microcoded, bipolar slice microengine that performs over 7 million instructions per second. As options, the IEEE 488 or RS 232C interfaces are available. Standard features of the MIDAS 500 include modular optics that allow fields of

view ranging from a few square feet to fractions of an inch, a solid-state image sensor, and retrainable software.

For more information, contact: Donald C. Mead, Recognition Systems Inc., 15531 Cabrito Road, Van Nuys, CA, 91406. Phone: 213/785-2179. **CIRCLE 2**



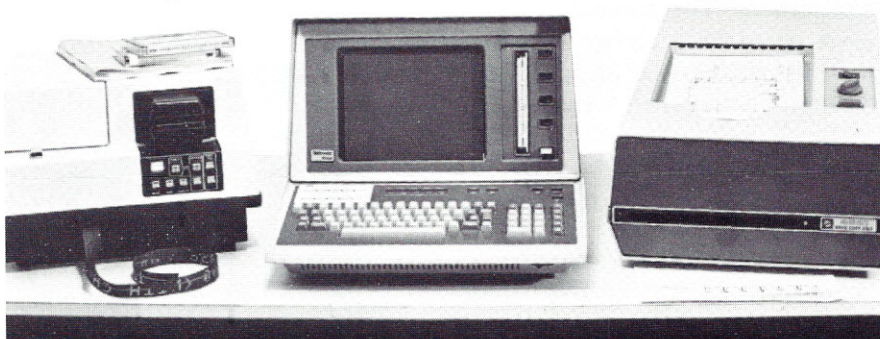
Small DC Motors Designed for Robots

A family of lightweight DC servo motors, designed for robots, is available from Magnetic Technology. The smallest MAGTECH motor measures 1.31" by 1.75" and produces 25 ounce-inches of torque. Its moment of inertia is .00036 oz-in-sec², allowing no-load acceleration to be nearly 70,000 rad/sec².

Other units in this series produce 50, 75, 140, and 300 oz-in of torque. The largest of these motors measures 3.1" in diameter by 4.5" in length.

All MAGTECH motors feature welded commutator connections, 180°C insulation, complete impregnation of windings, and brushes that are replaceable from outside the units.

For more information and literature, write: Magnetic Technology, Division of Vernitron Corporation, 21001 Kittridge Street, Canoga Park, CA, 91303. **CIRCLE 3**



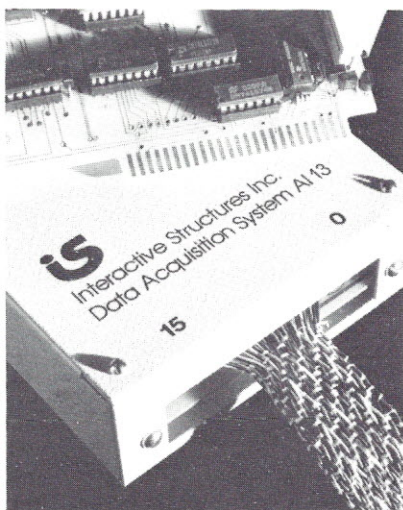
System Prepares NC Tapes

HINDS International announces PREP MASTER, a self-contained NC Tape Preparation System. The system—which incorporates a high-resolution graphic desktop computer—produces tapes for any two-axis NC machine. The user builds the part to be machined from the drawing to the screen with a drawing control button. Errors are

detected and corrected via the input keyboard during tape preparation. The operator can magnify for closer inspection any part or section and can call on the screen any standard tool shape.

For more details, contact: Jimmie Moglia, HINDS International Inc., P.O. Box 4327, Portland, OR, 97208. Phone: 503/ 234-7411.

CIRCLE 4



Analog Input System

The AI13 Analog Input System, from Interactive Structures Inc., is a

data acquisition system for the IS1 and Apple Microcomputers. The AI13 features 16 analog input channels, 12-bit precision, 20 ms conversion time, eight software-selectable voltage ranges, use from BASIC and assembly language, and external trigger/interrupt capability. Full 12-bit operation is guaranteed over a 0 to 70°C range.

The AI13 interface board occupies a single expansion slot in the computer. A small metal cabinet, connected to the interface by a 24" cable, contains the input circuitry. Inputs are attached using a multi-channel cable that is included with the system.

For additional data, contact: Interactive Structures Inc., 112 Bala Avenue, Box 404, Bala Cynwyd, PA, 19004. Phone: 215/667-1713.

CIRCLE 5

A/D Conversion in 800 nsec

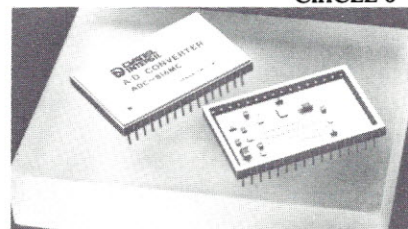
Datel-Intersil's new ADC-816 10-bit A/D converter has a maximum conversion time of 800 nsec over its full operating temperature range. The ADC-816 features 6 input voltage ranges: 0 to -5V, 0 to -10V, 0 to -20V, +2.5V, +5V, and +10V, by external pin connection. Data outputs are positive logic straight binary and offset binary in serial format, and two's complement in parallel format. For synchronization of serial data, a clock output produces a train of positive going pulses. In addition, a voltage reference output supplies -10V at 20mA for external use.

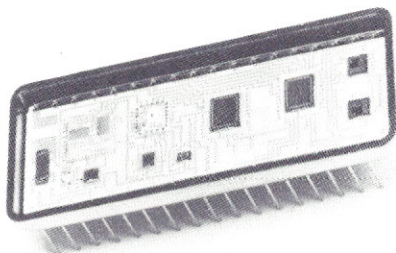
Other specifications include $\pm 1/2$ LSB differential and integral linearity errors, $\pm 37\text{ppm}/^\circ\text{C}$ maximum gain tempco, and $\pm 12\text{ppm}/^\circ\text{C}$ of full scale maximum zero tempco.

The converter requires +15 VDC and +5 VDC power supply inputs. There are three different versions for the following operating temperature ranges: 0 to 70° (ADC-816MC), -25°C to +85°C (ADC-816MR), and -55° to +125°C (ADC-816MM). In addition, there are units available with MIL-STD-883 Class B screening for military and aerospace applications.

Pricing on the ADC-816MC is \$245.00 in 1-24 quantities and \$196 in 100 piece quantities. Availability is stock to 4 weeks. The technical contact is: Ted Petit, Datel Intersil, 11 Cabot Boulevard, Mansfield, MA, 02048. Phone: 617/ 339-9341, X-211.

CIRCLE 6





Hybrid D/A Converter is Microprocessor Compatible

Natel Engineering Co. offers a new 4-quadrant multiplying digital-to-sin/cos converter. This device, the HDSC2016, features 8 and 16-bit microprocessor compatibility in a hybrid package.

the HDSC2016 has an angular accuracy of 2 arc-minutes and a radial accuracy of 0.03%. Packaged in a standard 36-pin DDIP, it is pin-programmable for gains of 0.5, 1.0, and 2.0. It requires a +15V power supply and has double buffered inputs. Two programmable input registers (buffers) permit the converter to interface with a microprocessor data bus.

The HDSC2016 costs \$345 in quantities of 1-9. Availability is stock to 6 weeks. For more details, get in touch with: Natel Engineering Co., 8954 Mason Avenue, Canoga Park, CA, 91306. Phone: 213/ 882-9620.

CIRCLE 7

16 Bit Synchro-to-Digital Converter Features Built-In Test

A new 16-bit synchro/resolver-to-digital converter is now available from Natel Engineering. Called the SRD546, it features 1 arc-minute accuracy and a built-in test feature.

The test feature provides a logic one when the tracking error exceeds $\pm 1^\circ$. An automatic gain compensation circuit allows signal voltage variations of $\pm 30\%$ without degradation in accuracy or change in converter hysteresis.

Pin-programmability is included for both synchro and resolver inputs as well as line-to-line signal voltages of 11.8, 26, and 90 Vrms. Both signal

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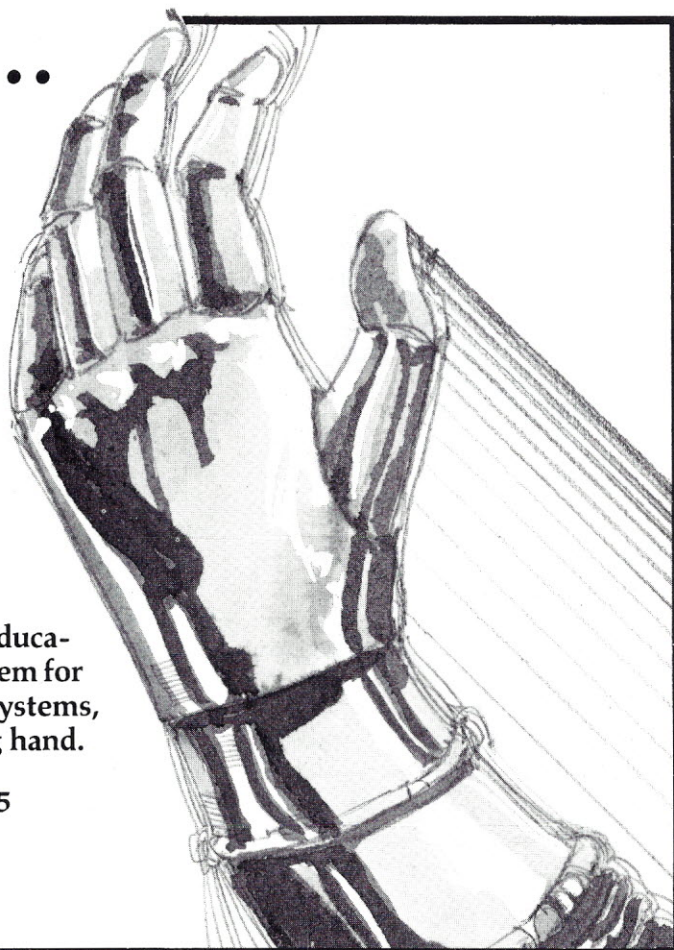
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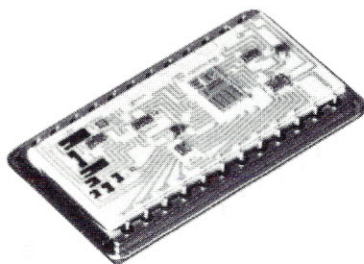
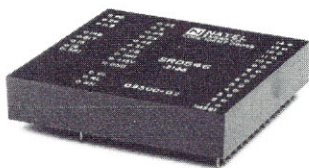
CIRCLE 27



and reference inputs are transformer isolated and provide high common mode rejection. Operating from a reference voltage of 10 to 130 Vrms, the SRD546 is both TTL and CMOS compatible. the output is programmable for CMOS output levels up to the main supply (+15V). A holding register allows the user to inhibit the output without interrupting the converter loop.

For quantities of 1-9, the SRD546 costs \$695. Its availability is stock to 6 weeks. For more details, contact: Natel Engineering Co., 8954 Mason Avenue, Canoga Park, CA, 91306. Phone: 213/882-9620.

CIRCLE 8



D/A Converter Operates Over Wide Temperature Range

ILC Data Device Corporation offers a 12-bit hybrid D/A converter that operates over a temperature range of -55°C to +125°C and has a 3,000,000 hour mean time between failures. Called the DDC DAC87, it was designed as a replacement for

industry standard DAC85 and DAC87.

The DDC DAC87 features $\pm \frac{1}{2}$ LSB linearity error, 6MHz throughput rates, and guaranteed monotonicity. It comes in two models: a voltage output version, DDC DAC87-CBI-V, and a current output unit, DDC DAC87-CBI-1. The voltage output unit has five pin-programmable output ranges: +2.5, +5, +10, 0 to +10, and 0 to +5. The DDC DAC87-CBI-1 has a 100ns current settling time. The DDC DAC87-CBI-V has a 3 sec voltage settling time.

The DDC DAC87 operates from +15, -15, and +5V power supplies. It is sealed in a 24 pin DDIP package. The converter's input is TTL compatible, requiring one standard TTL load drive capability and accepting binary and complimentary offset binary codes.

The DDC DAC87 is priced at \$93 per unit in 100 quantities. Delivery is stock to 4 weeks. Additional information can be obtained from: Bill Cullum, ILC Data Device Corporation, 105 Wilbur Place, Bohemia, NY, 11716. Phone: 516/567-5600.

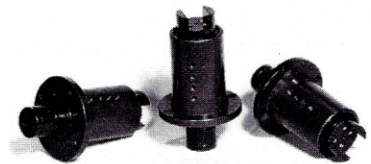
CIRCLE 9

Robot Bearing/Rotating Union

Scott Engineering offers a new bearing/rotary union designed for pick-and-place robot applications. The union combines the robot arm bearing assembly with a 4-port, low friction, flangemounted rotating union. At its lower end, the bearing/rotary union provides for a slip ring assembly and stepper motor drive. At the top, a slot provides for robot arm attachment and connections to the air cylinders.

Custom design arrangements are available. For further information, contact: Scott Engineering Company, 430 North 9th Street, Olean, NY, 14760. Phone: 716/372-5690.

CIRCLE 10



Free Technical Literature

Data Translation offers a 12-page manual that presents configurations, capabilities, and applications for the MULTIBUS-compatible MIDAX family of data acquisition and control systems. A hardware configuration guide gives key system specifications, while a software guide describes the installed, ROM-resident firmware package, DTFIRM, a standard feature in all MIDAX systems.

The editorial contact for the manual is: Bill Miller, Data Translation, 100 Locke Drive, Marlboro, MA, 01752. Phone: 617/275-2846.

CIRCLE 11



Second Edition of Industrial Robot Book Released

The Society of Manufacturing Engineers (SME) and Robotics International (RI) of the SME have now made available the second edition of *Industrial Robots*. This two-volume set—*Fundamentals* and *Applications*—has been updated to reflect technical advances made since 1978, when the first edition was published.

Volume I, *Fundamentals*, discusses the basics, implementation, justification, human factors, capabilities, and advanced technology of robotics. Volume II, *Applications*, investigates specific cases of robots used in material handling, machine loading, die casting, forging, welding, assembly, and so on.

Prices are \$32.00 per volume for RI/SME members and \$37.00 per book for others. Orders can be placed with SME's Publication Sales Department, One SME Drive, P.O. Box 930, Dearborn, MI, 48128. Phone: 313/ 271-1500, Ext. 346.

CIRCLE 12

Publisher Offers Brochure

Leading Edge Publishing has a new brochure available, listing current volumes of interest to manufacturing management. Among these are *A Survey of Industrial Robots*, *A Survey of Commercial Turnkey CAD/CAM Systems*, and *Management's Guide to Computer Integrated Manufacturing*.

Information about these and other publications is available from the publisher: Leading Edge Publishing, 5622 Dyer Street, P.O. Box 8100, Dallas, TX, 75205. Phone: 214/739-0340.

CIRCLE 13

New Robotics Society Forms

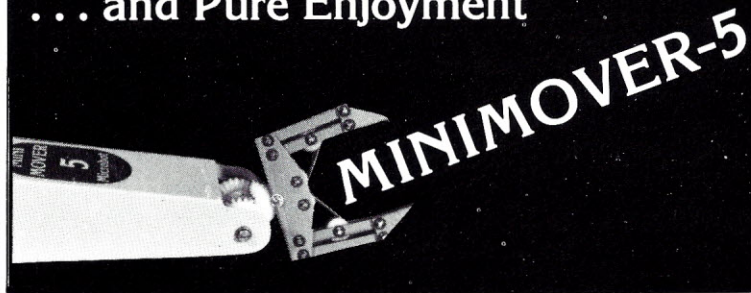
The American Robotics Society, a non-profit organization dedicated to the advancement of research and industrial robotics application, is offering membership to anyone interested in Artificial Intelligence and Robotics. Membership and publications fee is \$20.00 for non-students and \$15.00 for students. Contact: The American Robotics Society, 104 Charles St., Box 190, Boston, MA, 02114.

CIRCLE 14

New Products Policy

ROBOTICS AGE encourages the manufacturers of products related to robotics and automatic control applications to send in New Product announcements for this department. Readers are advised that, although *ROBOTICS AGE* selects new products for publication based on our estimation of their relatedness to the field, in most cases we have not evaluated either the product or the company and, although we would not knowingly print any inaccurate information, no endorsement of any product is implied. Send announcements of New Products literature to *ROBOTICS AGE*, New Products, PO Box 801, La Canada, CA 91011.

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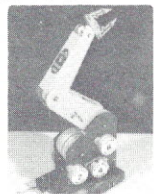
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CIRCLE 28

ORGANIZATIONS

Carnegie Mellon Offers New Computer Chess Prize

Carnegie-Mellon University recently announced two new prizes for computer chess. These awards supplement the \$100,000 prize established last year by the Fredkin Foundation for the first computer program to defeat a human World Chess Champion.

A prize of \$5,000 will be awarded for the first computer program to attain a Master rating in competition with human players. Another \$10,000 will go for the first program to attain a Grandmaster rating. Grandmaster is the highest ranking in human competition. There are fewer than 200 Grandmasters in the world. Master ranking is below that. There are about 200 Masters in the United States.

To claim the prize, a program must play at least 25 games in official competition against humans. The current computer World Champion is BELLE, written by Ken Thompson and Joe Condon of Bell Labs in Murry Hill, New Jersey. BELLE is expected to achieve Master level this year and claim the \$5,000 prize.

In August, a two-game match for \$2,000 was held at the International Joint Conference on Artificial Intelligence (IJCAI) in Vancouver, British Columbia. In this contest, BELLE faced Canadian Master Carl Storey. Mr. Storey won both games decisively.

Last year, there were two sets of matches between computers and human players of Expert ranking (a level below Master). In these games, which were part of the Fredkin prize, the computers won one match and drew the other.

Public Robot Exhibition Slated for Next Summer

The California Academy of Sciences and International Robot Events, Ltd., plan to hold the First International Robot Exhibition in the summer of 1982. Held at the Academy in Golden Gate Park, San Francisco, the exhibition will run for about six months.

The exhibition's planners expect to include exhibits of industrial robots, robots built by individual inventors, and the latest advances in robotic technology and artificial intelligence. They also plan to include a workshop on "how to build a robot," and a multi-media show on the history and current trends in robotic technology.

Calendar

The **11th International Symposium on Industrial Robots (ISIR) and Robot Exhibit** will be held October 7-12, 1981, in Tokyo, Japan. The symposium, entitled "The Human Age in Robots," will feature the latest worldwide developments in robotic technology. Also scheduled are tours of several Japanese companies that use robots.

ISIR will cover robotics in general, software research and development, production systems design, and applications and operating experience. The symposium will also examine the "new philosophies" surrounding the growing use of industrial robots and the impact of

robots on human and social issues.

The symposium is organized by the Japan Industrial Robot Association (JIRA) and the Society for Biomechanisms, Japan. It is co-sponsored by the Robot Institute of America (RIA). For registrants from the US, the RIA has organized a travel group and post-symposium tour. Participants will visit the facilities of important researchers, users, and manufacturers of robots. Among those visited will be Toyota Motor Co., Mitsubishi Motor Corporation, and Fujitsu-Fanuc Ltd.

The symposium will also feature the 1981 Engelberger Awards, honoring excellence in robotics technology development, applications, and education. The award is named after Joseph Engelberger, president of Unimation Inc. and acknowledged "father of industrial robots." For further information on registration and itineraries, contact Paul von Jankowsky, RIA Headquarters, One SME Drive, P.O. Box 930, Dearborn, Michigan, 48128. Telephone: 313/ 271-1500, ext. 410.

The IEEE Systems, Man, and Cybernetics Society will sponsor the **1981 International Conference on Cybernetics and Society (ICCS)** on October 26-28 at the Sheraton-Atlanta Hotel. More than 175 professional papers will be presented by individuals representing a variety of countries and scientific disciplines, including engineering, computer science, and psychology.

The technical program will consist of paper presentations and panel discussions. Among the topics are

(continued pg. 45)

MEDIA SENSORS

Business Week, August 17, 1981.

Russian Robots Run to Catch Up. The Soviet Union is determined to catch up to the West in industrial robots. In robotic technology, most experts consider the Soviets 5 to 10 years behind the US, Western Europe, and Japan. But in the number of installed robots, Russia may already rank third. And it plans to be second by 1985.

After 13 years of building robots, the Soviets have installed between 6,000 and 7,000 units. By Western standards, most of these machines are technologically primitive. Most of them have only three or four axes, and most are pneumatically or hydraulically powered. Russia does not produce fine-tuned lightweight electrical motors.

Above all, the Soviets lag the West in advanced electronics. Among all their robots, the Russians have only 2000 with programmable controllers. A mere 200 have some kind of sensory feedback. Increasing the number of programmable robots will be the highest priority during 1981-1986. In the five-year plan after that, the emphasis will be on robots with sensory feedback.

The Soviets see robots as the solution to two problems that plague their economy: a manpower shortage and poor labor productivity—the lowest in the industrial world. So at this year's 26th Congress of the Communist Party, Leonid Brezhnev announced his plans to have 22 ministries build 40,000 robots over the next five years. If this plan is successful, the number of soviet robot installations will increase nearly 50% annually through 1985. By then, the Soviets plan to have robots do the work of

120,000 humans.

OMNI, August, 1981, **Talking Tombstone.** The "silence of the grave" may soon be broken by the latest speaking product—the talking tombstone. Created by Fidelity Monument Works, the solar-powered tombstone delivers a 90-minute message to anyone who activates it. Its price is \$10,000.

Though they refuse to describe the electronics buried in the device, the inventors do talk about the body: a metal tube, four inches in diameter and twelve inches long. At one end lies a device that reproduces the deceased person's voice (or a eulogy about him). At the other end lies the actuating mechanism.

Fidelity Monument Works guarantees that the tombstone will operate for two generations—about 40 years. So far, though, the company has sold only one unit. It is buried in a monument to the dead of World War II.

World Press Review, August, 1981, **Japan's Robot Revolution.** Japan's successful marketing of cars, electrical appliances, and other products is increasingly due to the industrial robot. In Toyota Motor Company's new Tahara No. 2 plant, for example, robots work in every stage of production. Eighty robots labor on the welding line, performing eighteen separate processes, each in three minutes.

Using robots has drastically reduced the number of human workers needed to build cars. Toyota claims that their robotic welding line has eliminated more

than fifty human laborers. Only one human remains—an overseer stationed at the end of the line. At Honda Motor Company's highly automated Sayama Works, eight robot painters have completely replaced human labor.

But robots do more than cut back on labor. The Japanese use robots primarily to improve the quality and the ability to customize their products. Consider a plant at Fujitsu-Fanuc. There, robots build other robots and numerically controlled (NC) machine tools 24 hours a day. though fewer than 10 robots work in the plant, its monthly production is almost \$8 million.

The companies discussed so far—Toyota, Honda, and Fujitsu-Fanuc—are industrial giants. But the use of robots is not limited to large companies. In fact, small and medium-sized operations use almost 70% of all welding robots. Even small family-owned factories are beginning to automate. A cottage-sized workshop can afford to use a \$40,000 robot in place of a human and recover its investment in just a few years.

The Japanese robot business is flourishing. The Momura Research Institute predicts that, by 1985, Japan's robot industry will achieve sales of \$1.2 billion. By 1990, that figure could reach \$2.4 billion. Other predictions are even more optimistic. They claim that the industry will continue its 40-50% annual growth. this means that, by 1990, total robot sales could reach \$4 billion.

Short on Computer Power? Does
(continued pg. 45)

TECHNICAL ABSTRACTS

Three Short Essays on Decisions, Reasons, and Logics, by Jon Doyle, May 1981, 19 pages, (STAN-CS-81-864, \$2.60).

This report collects together three short, survey-level essays introducing related approaches to decision-making, reasoning, and logic. The first essay, *Making Difficult Decisions*, was read to the Stanford Computer Forum on February 5, 1981. The following two essays, *Dependencies and Assumptions* (written with Johan de Kleer) and *Non-Deductive Reasoning and Non-Monotonic logics*, are versions of articles to appear in the *Handbook of Artificial Intelligence* (A. Barr, P. Cohen and E. Feigenbaum, eds.).

Symbolic Reasoning Among 3-D Models and 2-D Images, by Rodney A Brooks, June 1981, 181 pages, (STAN-CS-81-861 \$7.45).

An implemented and operational model-based vision system is described. Examples are given of its interpretation of images, including extraction of three-dimensional parameters from monocular images. Advances are presented in representation for geometric modeling of objects and object classes, in techniques for manipulating non-linear symbolic algebraic constraints, in geometric reasoning in incompletely specified situations, and in constructing algebraic constraints from image measurements. Both generic object classes and specific objects are represented by volume models which are independent of viewpoint.

Complex real-world object classes are modeled. Variations in size, structure and spatial relations within

object classes can be modeled. New spatial reasoning techniques are described which are useful both for prediction within a vision system, and for planning within a manipulation system. New approaches to prediction and interpretation are introduced, based on the propagation of symbolic constraints.

Predictions are two-pronged. First, prediction graphs provide a coarse filter for hypothesizing matches of objects to image features. Second, prediction graphs contain instructions on how to use measurements of image features to deduce three-dimensional information about tentative object interpretations. Interpretation proceeds by merging local hypothesized matches, subject to consistent derived implications about the size, structure and spatial configuration of the hypothesized objects. Prediction, description and interpretation proceed concurrently, from coarse object subpart and class interpretations of images, to fine distinctions among object subclasses, and more precise three-dimensional quantification of objects.

A Programming and Problem-Solving Seminar, by Donald E. Knuth and Allan A. Miller, June 1981, 84 pages, (STAN-CS-81-863, \$4.50).

This report contains edited transcripts of the discussions held in Stanford's course CS 204, Problem Solving Seminar, during autumn quarter 1980. Since the topics span a large range of ideas in computer science, and since most of the important research paradigms and program-

ming paradigms came up during the discussions, the notes may be of use to graduate students of computer science at other universities, as well as to their professors and to professional people in the "real world."

The thesis also addresses an important issue in current automatic planning research: production not just of a correct solution but of a "good" one, by means of an efficient problem solver. Semantic query optimization advances the notion of a *problem reformulation* step for problem-solving programs. In this step, equivalent statements of the original problem are sought, one of which may have a better solution than the original problem. This method avoids explicit and possibly costly analysis of efficiency factors during planning itself.

Query Optimization by Semantic Reasoning, by Jonathan Jay King, May 1981, 128 pages, (STAN-CS-81-857, \$5.85).

This thesis presents a new approach to the problem of database query optimization, called *semantic query optimization*. The goal of semantic query optimization is to produce a semantically equivalent query that is less expensive to process than the original query. The knowledge used to transform a query is the same knowledge used to insure the *semantic integrity* of the data stored in the database. A system called QUIST (QUery Improvement through Semantic Transformation) is described that carries out semantic query optimization for an important class of relational database queries. For many queries, QUIST can achieve

substantial reductions in the cost of retrieval. It does this at a negligible cost for its analysis by relying on heuristics based on knowledge of database access and structure.

ADAM - An Ada based Language for Multi-processing, by Luckham, Larsen, Stevenson and von Henke, July 1981, 71 pages, (STAN-CS-81-867, \$4.15).

Adam is an experimental language derived from Ada. It was developed to facilitate study of issues in Ada implementation. The two primary objectives which motivated the development of Adam were: to program supervisory packages for multitask scheduling, and to formulate algorithms for compilation of Ada tasking.

Adam is a subset of the sequential program constructs of Ada combined with a set of parallel processing constructs which are lower level than Ada tasking. In addition, Adam places strong restrictions on the sharing of global objects between processes. Import declarations and propagate declarations are included.

A compiler has been implemented in Maclisp on a DEC PDP-10. It produces assembly code for a PDP-10. It supports separate compilation, generics, exceptions, and parallel processes.

Algorithms translating Ada tasking into Adam parallel processing have been developed and implemented. An experimental compiler for most of the final Ada language design, including task types and task rendezvous constructs, based on the Adam compiler, is presently available on PDP-10's. This compiler uses a procedure call

implementation of task rendezvous, but will be used to develop and study alternate implementations.

Toward A Unified Logical Basis for Programming Languages, by Chih-sung Tang, June 1981, (STAN-CS-81-865, \$2.65)

In recent years, more and more computer scientists have been paying attention to temporal logic, since there are many properties of programs that can be described only by bringing the time parameter into consideration. But existing temporal logic languages, such as Lucid, in spite of their mathematical elegance, are still far from practical. I believe that a practical temporal-logic language, once it comes into being, would have a wide spectrum of applications.

XYZ/E is a temporal-logic language. Like other logic languages, it is a logic system as well as a programming language. But unlike them, it can express all conventional data structures and control structures, nondeterminate or concurrent programs, even programs with branching-time order. We find that the difficulties met in other logic languages often stem from the fact that they try to deal with these structures in a higher level. XYZ/E adopts another approach. We divide the language into two forms: the internal form and the external form. The former is lower level, while the latter is higher. Just as any logic system contains rules of abbreviation, so also in XYZ/E there are rules of abbreviation to transform the internal form into the external form, and vice versa. These two forms can be considered to be different

representations of the same thing. We find that this approach can ameliorate many problems of formalization.

Research on Expert Systems, by Bruce G. Buchanan, February 1981, 38 pages, (STAN-CS-81-837).

All AI programs are essentially reasoning programs. And, to the extent that they reason well about a problem area, all exhibit some expertise at problem solving. Programs that solve the Tower of Hanoi puzzle, for example, reason about the goal state and the initial state in order to find "expert-level" solutions. Unlike other programs, however, the claims about expert systems are related to questions of usefulness and understandability as well as performance.

As a part of our goal of disseminating current technical information to our readers, this department will list abstracts of significant recent technical papers, in cases where these papers are available to the public. The relevant addresses will normally be listed after the abstracts. We urge academic and industrial research centers to send us abstracts of recent papers in Robotics and Artificial Intelligence for possible inclusion in this department, with appropriate prices and ordering procedures.

Digital Image Processing

Rafael Gonzalez and Paul Wintz, Addison-Wesley (Advanced Book Program), 1979, 431 pages, paper, \$19.50.

This book introduces the basic concepts and techniques used in digital image processing. Though it focuses on fundamentals, it also gives examples of their use in real applications. The authors intended it as a senior or first year graduate textbook for an image processing course. And they assume that the reader has some familiarity with computer programming, mathematical analysis, and probability.

Image digitization has been in commercial use for nearly sixty years. As early as the 1920's, the Bartline transmission system digitized photographs to five grey levels and sent them over telegraph lines. Computer techniques for improving images were introduced in 1964, when they were applied to Ranger 7's pictures of the moon. Today, image processing has two major applications: enhancing pictures for human viewing, and analyzing images for machine visual perception (pattern recognition). This book deals mostly with image enhancement.

Digital Image Processing starts, tamely enough, with non-mathematical background material. In chapter 1, the authors give a short history of the field and tell why image processing has become such an important technology. The second chapter covers the human vision system, conventional photography, and image quantization.

In chapter 3, the authors begin to develop the mathematics essential for understanding this subject. They begin with the two-dimensional

Fourier transform. Since they present only those aspects of the transform that directly relate to image processing, much of the formal mathematical detail is left out. The result, though still quite technical, is relatively easy to follow. Especially helpful are the illustrations of Fourier transform pairs and the FORTRAN listings of various transform subroutines.

After giving the mathematical background, Gonzalez and Wintz discuss image enhancement. Chapter 4 covers enhancement techniques such as histogram modification, smoothing and sharpening, and pseudo-color. A large number of illustrations, both plots and processed images, greatly help the reader visualize the effects of each operator. This chapter contains seven color plates, including a chromaticity diagram and an example of color-tagged spatial frequencies. Image enhancement, allied with computer graphics, may become a major tool for artists and animators in the next decade.

The chapter on image restoration concentrates on theory. The only application it mentions is the removal of noise from space-probe photographs.

A chapter is devoted to image encoding, also called image compression. Since digital images use up large quantities of memory and are expensive to transmit, data reduction is crucial. Among the techniques covered are: differential encoding in LANDSAT's multispectral images, run-length encoding in river flood maps, hybrid encoding for remotely piloted aircraft, and imperfect (low fidelity) encodings.

The discussion of feature extraction for image compression naturally leads to the subject of

image description—where meaning is extracted from a picture. The authors describe how to use critical features, such as corners or straight line segments. These features can help isolate objects from the background and even give information for interpretations such as "the man is smiling" or "the car is upside down." The techniques in this chapter are often the first phases of automatic scene analysis programs.

To go further would lead us to artificial intelligence techniques—beyond the scope of this book. These topics are covered in a companion volume, *Syntactic Pattern Recognition* by Rafael C. Gonzalez and Michael Thomason, Addison-Wesley publishers.)

Digital Image Processing is the best introductory text on this subject that I have seen. There has been enough work in the field to have established a good foundation of fundamental concepts. And Gonzalez and Wintz have covered most of them. I recommend this book to anyone who wants to learn the fundamentals of computer vision and image processing.

—Reviewed by Donald J. Christian

LETTERS

Radio Shack Replies

Your reply to reader McClennen's missive (*May/June 1981*) suggested a substitution chart for semiconductors. I would like to refer you to our Archer Semiconductor Reference Handbook, stock #276-4004 (\$2.99). It crosses over 100,000 types.

Of course, even without this guide, the proper part can be easily determined using basic current, voltage, power and gain characteristics of the circuit and the device. To this end, we have recently introduced a cardboard "Ohm's Law Calculator" slide rule (271-1211, \$.49).

Loofbourrow's PWM circuit calls for the following parts (our suggested current substitute and price is shown in parentheses):

RS-2006 (276-2040 @ \$2.19)
RS-2012 (276-2031 @ .89)
HEP S0019 (276-2034 @ .79)
SK3036 (276-2039 @ 2.19)
10A 100V diode
(nothing available at this time)
1A 100V diode ... (276-1102 2/.59)
7A dpdt 12V relay
(275-218 @ 5.99)

Of course, updating to VMOS would simplify the drive circuitry and obviate the flyback diodes. We offer the VN67AF 15 Watt Power FET (276-2071) for \$2.49.

Radio Shack supports the basic electronics needs of robot experimenters and builders—and we promise some news in the not-too-distant future about new ways we'll be offering even more. One recent example is our 100K joystick pot (271-1705, \$4.95). Digitize its outputs for robot control or position feedback or hang a weight pendulum-style for tilt-angle sensing. And we will continue to offer infrared, Hall-effect, A/D, D/A and

other needed devices—but we will not be changing our name to Robot Shack.

Martin Bradley Winston
Director of Publicity
Radio Shack
1300 One Tandy Center
Fort Worth, TX 76102

Thanks, Marty—It's good to know we have a robot hacker in a strategic place to point out robotics-related opportunities to Tandy/Radio Shack. (Writing as M. B. Weinstein, Winston has been a contributor to ROBOTICS AGE (Jan/Feb '81 and March/April '81) and is the author of Android Design (Hayden Books)).—AMT

Seeks Graduate Work In Robotics

I am an undergraduate Mechanical Engineering student at Tri-State University in Angola, Indiana. I will graduate in May '82 and would like to continue on to graduate school. I am having trouble finding out what schools have programs geared specifically towards Robotics. Any information you could give would be greatly appreciated.

Matt Ellis
4741 Birch Haven Rd.
Jackson, MI 49201

We've had a number of requests from students looking for a good grad school where they can pursue their interest in Robotics. Unfortunately (or fortunately), there are now really too many excellent groups to list them all. Many readers are familiar with the work at Stanford (professor to contact: T. Binford), MIT (P. Winston), Purdue

(R. Paul), and the new Robotics Institute at Carnegie-Mellon (R. Reddy). But there are also strong groups going at U. Rhode Island (J. Birk), Rensselaer Polytechnic Inst. (G. Saridis), U. Central Florida—Orlando (C. Bauer), U. Florida—Gainesville (D. Tessar), U. Utah (D. Allen), U. Calif.—Berkeley (D. Dornfeld), and many others.

Since my list is far from complete, may I suggest to any research group whose name I've omitted that they drop us a line and let us know about their projects? We will print all responses in our Letters Dept. and possibly feature your work in an article. Remember that there are thousands of students reading ROBOTICS AGE who are eager to join your groups!—AMT

Comments on "Computer Controlled Lathe"

I enjoyed the article by Jan Rowland (*May/June '81*). We've been building an animation camera stand controlled by an Apple, and several points in the article paralleled our activity. A couple of suggestions occurred to me for Jan and anyone else working with similar devices.

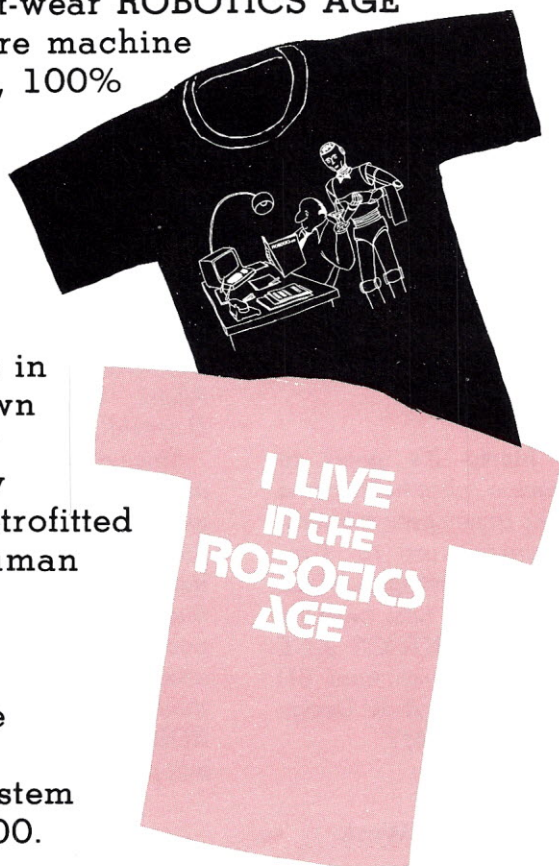
Limit switches could be helpful both for safety and for resetting equipment to a well-defined start position. I recommend using solid-state (hall-effect) switches and shielding all lines to the computer. The game paddle I/O port is an easy place to connect two or three inputs.

As to the problem of controlling xy paths that are not expressible in simple equations, one solution could be using a digitizing pad to enter a complex curve that the computer could then approximate and follow.

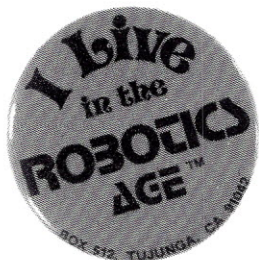
Also, another good source of small electro-mechanical parts is SECS,

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19-36 38th St., Long Island City, NY 11105, (212) 932-4545.

Phil Denslow
955 N. Normandie
Los Angeles, CA 90029

More on "Video Signal Input"

I have some questions about the video signal digitizer featured in your March/April '81 issue. Specifically, I would like to know whether I could increase the gray-scale resolution from two to sixteen levels by using more circuitry. Also mentioned in the article was a board called the "Digisector," which would apply to what I am doing. Speed in image digitizing is not too critical in my case. I am an artist involved with electronic sculpture and my latest piece of cybernetic art depends upon your reply.

Ruben Rodziewicz
DAC Systems
544 Strathmore Blvd.
Toronto, Ontario
Canada M4C 1P1

You can easily get higher gray-scale resolution using Ray Eskenazi's thresholding digitizer if you make multiple scans of the same scene. Since it uses 8-bit DACs for the threshold values, you can (theoretically) get 8-bit resolution (256 gray levels) in the digitized image by incrementing the threshold by one on each scan.

To get a 4-bit gray-scale (16 level) digitized image, allocate an image array of (at least) 4-bit pixels and initialize it to all zeros. Set the upper threshold to 255 and the lower one to 16, then digitize a binary image into a bit array. (Ray's circuit also lets you define the dimensions of the digitized image.) Every nonzero pixel is above the lower threshold, so add one to its gray-level in the 4-bit

(continued pg. 45)

Organizations

(continued from page 38)

pattern recognition, artificial intelligence, man-machine systems, CAD/CAM, and robotics. For more information, contact: Dr. Joanne Green, Georgia Institute of Technology, Engineering Experiment Station/SEL, Atlanta, Georgia, 30332.

A one day seminar, **Industrial Robot Applications**, has been scheduled for October by the American Institute of Industrial Engineers (AIIE). The seminar will take place in Minneapolis and two California locations.

The Twin city AIIE Chapter will host an October 12 offering of the seminar at the Bloomington Marriott Hotel. The Los Angeles AIIE Chapter hosts an October 14 seminar at the Los Angeles Airport Hyatt. And the Peninsula and San Francisco-Oakland AIIE Chapters jointly host an October 15 offering at the Sunnyvale Hilton Inn, Sunnyvale, California.

Highlights of the seminar include information on robot structures, capabilities, and principal applications; a review of commercially available robots, the industrial engineer's role in robot applications, robot workplace layout design, impact on labor and management, and future trends; and a workshop on specific applications. The Institute encourages participants to bring sample parts, floor plan layouts, or slides or 16mm film of any application they wish to review during the workshop.

For more information, contact the AIIE Conference Dept., 25 Technology Park/Atlanta, Atlanta, Georgia, 30092. Phone: 404/449-0460.

Previously Announced:

Robots VI, March 1-4, 1982, Detroit, MI, Announced in Vol. 3, No. 4.

Autofact III, November 9-12, 1981, Detroit, MI. Announced in Vol.3, No. 4.

Media Sensors

(cont. from pg. 39)

your micro lack the processing power to control a robot? Take heart. In *Machine Design*, July 23, 1981, we found some good news for you: Boeing Computer Services now offers access to a Cray-1 supercomputer. The Cray-1 performs millions of instructions per second and has one million words of main memory. Currently it is used for tasks such as simulating nuclear explosions. Surely a robotics hobbyist can make better use of the Cray-1's power.

Media Sensors are brief summaries of robotics-related items that have appeared in the mass media. An attempt is made to paraphrase the content of the original item without altering the tone. The views expressed in these items are not necessarily those of *Robotics Age*. If you have an item you would like to contribute, send it along with a complete identification of its source, to:

Media Sensors
Robotics Age
P. O. Box 725
La Canada, CA 91011

Bookshelf

(cont. from pg. 29)

Understanding IC Operational Amplifiers, by Roger Melen and Harry Garland, Howard W. Sams & Co., Inc.

IC Timer Cookbook, by Walter G. Jung, Howard W. Sams & Co. (1977).

The 555 Timer Applications Sourcebook, With Experiments, by Howard M. Berlin, Howard W. Sams & Co. (1976).

Digital Interfacing with an Analog World, by Joseph J. Carr, Tab Books (1978).

Letters

(cont. from pg. 44)

image. Repeat the process, adding 16 to the lower threshold each cycle, for a total of 15 cycles. You will now have gray levels from 0 to 15 in your gray-scale image array. If you use the digitizer's DMA capability, you could conceivably produce your 16-level image in $15/60 = .25$ sec.—if your software can scan a binary frame in the 16ms the digitizer needs to convert a frame.

A one-pass gray-scale digitizer is really quite a different circuit from the binary digitizer in Eskenazi's article. The CAT-100 is a "frame-grabber" 4- or 8-bit gray-scale digitizer with an on-board image memory, made by DVS, 441 California Ave., Palo Alto, CA 94306. The Digisector is an 8-bit "point-digitizer" made by The Micro Works, P. O. Box 1110, Del Mar, CA 92014.—AMT

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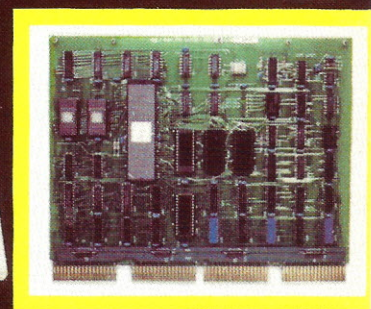
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